LOW RATES OF GLYPHOSATE FOR MANAGEMENT

OF *CYPERUS ROTUNDUS* L.

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ABSTRACT

Post-emergence applications of glyphosate (*N*-(phosphonomethyl) glycine) have not eradicated purple nutsedge (*Cyperus rotundus* L.) in the field. Possible reasons for this were investigated. Glyphosate at 1.0 and 2.0 kg ae/ha was applied to 6 week old purple nutsedge in the field. Tubers from different locations of the tuber system were sampled 3 weeks later and were sprouted in petri dishes at 23^{o} C with 100 ppm w/w benzyl adenine for 10 weeks. This experiment was conducted four times. Least sprouting occurred in the newly developing tubers with 29% and 8% sprouting at 1.0 and 2.0 kg/ha glyphosate respectively. Most sprouting occurred in tubers from parent tuber chains of two tubers with 71% and 52% sprouting at the two rates respectively. Basal bulbs responded similarly with 68% and 46% sprouting respectively at the two rates. Single parent tubers had 53% and 32% sprouting respectively for the two rates. June and October applications of glyphosate were more effective in reducing tuber sprouting than March application.

To estimate the proportion of different types of purple nutsedge tubers in the field, soil blocks from a 6 week old purple nutsedge stand were washed and the different types of tubers were categorized. The field contained an average of 5,000 tubers/m^2 in the upper 30 cm of soil. Of this 51% were from the parent population of tubers, 33% were basal bulbs and 16% were newly developing tubers. Of the parent population, 30% were unsprouted tubers with no aerial connections.

Forty six percent of the tubers in the parent population occurred singly. The rest were in chains of two or more tubers.

Glyphosate at low levels was tested for its effects on purple nutsedge tuber sprouting. Pots with 6 week old purple nutsedge were sprayed with 0.0, 0.25, 0.5, 1.0 and 2.0 kg/ha glyphosate. Tubers were sampled 3 weeks later and sprouted in petri dishes for 10 weeks. Sprouting of tubers was reduced by glyphosate rates of 0.5 kg/ha or more. Tuber sprouting at 1.0 kg/ha of glyphosate increased with increased ratio of tuber fresh weight to leaf fresh weight.

Field management of purple nutsedge in continuously cropped lettuce (*Lactuca sativa* L.) variety 'Manoa', continuously cropped green bean (*Phaseolus vulgaris* L.) variety 'Green Crop' and a rotation of the two crops under a conventional cultivation system was tested in a 13 month, six crop cycle experiment. Glyphosate at 0.5 and 1.0 kg/ha was applied post-harvest to crops. In addition, efficacy of glyphosate for management of purple nutsedge at 1.0 kg/ha under no-till was compared with the conventional cultivation system. Both the 0.5 and 1.0 kg/ha rates of glyphosate reduced purple nutsedge stand equally irrespective of the crop. Furthermore, purple nutsedge in glyphosate treated plots was shorter than those in untreated plots. Purple nutsedge in no-till plots was shorter than those in the rotovated plots with 1.0 kg/ha glyphosate. At the end of the sixth crop cycle, purple nutsedge tuber populations in the glyphosate treated plots and handweeded plots were 70% lower than the unweeded control. Glyphosate at 0.5 kg/ha was as effective as 1.0 kg/ha or handweeding in reducing the purple nutsedge tubers.

The fresh weight, dry weight and mean daily accumulation of dry matter of lettuce was reduced by purple nutsedge during the summer months. This was related to purple nutsedge plant height that increased with an increased air temperature. Therefore, control of purple nutsedge in lettuce 'Manoa' was necessary only during summer. The presence of purple nutsedge resulted in an increase in the fresh weight of lettuce because it retained more water than in the weed-free hand weeded plots.

Stand reduction of purple nutsedge with glyphosate at 1.0 kg/ha increased the fresh weight of lettuce from the second crop cycle. However, during September, when purple nutsedge had the highest plant height, lettuce yields were not increased in the 1.0 kg/ha glyphosate treatment plots. Under no-till, lettuce yield increased during the sixth crop cycle and decreased during the fourth crop cycle.

Bean yield was not affected by purple nutsedge at any time. Therefore, the control of purple nutsedge in bean 'Green Crop' seemed unnecessary.

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CHAPTER I

INTRODUCTION

Purple nutsedge (*Cyperus rotundus* L.) is a common weed in tropical cultivated lands. It is difficult to control because of the presence of underground corms and tubers that are propagules.

Glyphosate (*N*-(phosphonomethyl)glycine) at 2.0 and 4.0 kg ae/ha is used to control purple nutsedge (Baird *et al.*, 1971). However, these rates are expensive for the user and do not eradicate purple nutsedge. Low populations of purple nutsedge have been obtained with low rates of glyphosate (Doll and Piedrahita, 1982; Toth and Smith, 1979).

The objectives of this study were: 1) to characterize the inability of glyphosate to eradicate purple nutsedge, 2) to determine the effects of low levels of glyphosate on purple nutsedge, and 3) to determine the effectiveness of low levels of glyphosate applied post-harvest to bean (*Phaseolus vulgaris* L.), lettuce (*Lactuca sativa* L.), and a rotation of the two crops under conventional and no-tillage practices for purple nutsedge control.

CHAPTER II

REVIEW OF LITERATURE

Purple nutsedge (*Cyperus rotundus* L.) is the most common weed in tropical crops (Holm *et al*., 1977). It is a perennial and found throughout the warm regions of the world.

Biology of purple nutsedge

Purple nutsedge belongs to family Cyperaceae (Ranade and Burns, 1925). It propagates primarily by corms (basal bulbs) and tubers in an underground rhizome system (Ranade and Burns, 1925). Basal bulbs are those that bear leaves and inflorescences. Any underground propagule without leaves and inflorescences is a tuber. Propagation by seeds is not important because purple nutsedge produces few seeds and only a fraction of them is viable (Anderson, 1968; Justice and Whitehead, 1946; Keeley and Thullen, 1979; Ranade and Burns, 1925).

A purple nutsedge plant, begins as a vertically growing rhizome from a tuber (Ranade and Burns, 1925). Near the soil surface, the tip of the rhizome swells and forms a basal bulb. The basal bulbs produce leaves and inflorescences. After initial establishment, it produces new basal bulbs and tubers from horizontally growing rhizomes. The new basal bulbs and tubers, in turn, produce more rhizomes and continue the formation of the tuber system. Figure 2.1 illustrates the different tubers of a purple nutsedge plant.

New tubers begin forming about 3 weeks after initial shoot emergence (Ranade and Burns, 1925; Smith and Fick, 1937). However, in Georgia, new tubers appeared only 6 to 8 weeks after shoot emergence

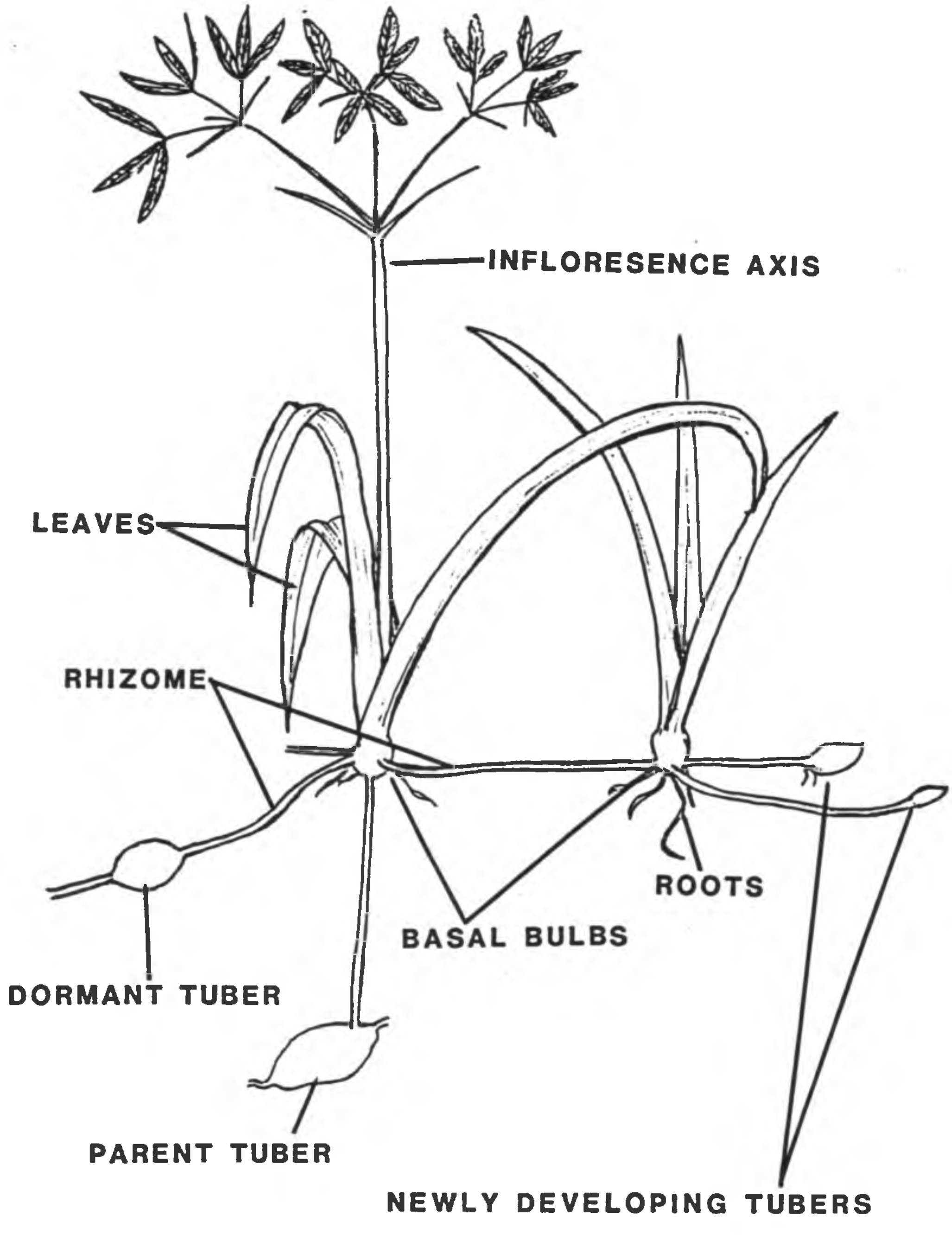

Figure 2.1. Structure of a purple nutsedge plant.

(Hauser, 1962). The tubers and basal bulbs store food, mainly as starch (Ranade and Burns, 1925; Wills and Briscoe, 1970).

Tuber production by purple nutsedge is rapid. In Georgia, tubers planted at 30 cm distances produced 3,090,000 plants and 4,420,000 tubers and basal bulbs per 0.4 ha in one growing season (Hauser, 1962). Tubers planted at 30 or 90 cm intervals produced 71 and 470 new plants per tuber respectively at the end of the first summer and 118 and 882 plants per tuber respectively at the end of the second summer. The tuber production rates at the end of the first summer were 63 per tuber at 30 cm intervals and 913 at 90 cm intervals.

In Arizona, pots maintained at minimum soil moisture levels of 6, 9, 12, 15 and 18% produced 28, 46, 65 and 82 tubers in 24 weeks (Davis, 1942). Tuber fresh weight increased from 0.9 g per tuber at 6% soil moisture to 1.6 g per tuber at 18% soil moisture.

Purple nutsedge subject to intraspecific interference partitioned more dry matter to tubers than to above ground parts (Williams *et al.*, 1977). Tuber production per plant and dry weight per plant also decreased under high intraspecific interference. These results are similar to those of Hauser (1962) who reported that fewer tubers per plant were obtained at a plant spacing of 30 cm than at 90 cm.

Rhizomes and tubers are white and succulent when new (Wills and Briscoe, 1970). They become hard and turn brown and rhizomes become wiry when old. However, the wiry rhizome is alive and interconnects all the tubers and basal bulbs in a plant.

Mechanical tillage of land breaks the interconnected basal bulbs and tubers and disperse them across the field. These propagules may establish new plants.

Sprouting of purple nutsedge tubers is not uniform. In Jamaica, 38% tuber sprouting occurred in September whereas, 83% of the tubers sprouted in June (Hammerton, 1968). The differential tuber sprouting was due to tuber dormancy. Tuber dormancy was related to the presence of salicylic acid (Berger and Day, 1967), abscisic acid (Jangaard *et al*., 1971) and inhibitor B (Teo and Nishimoto, 1973; Teo *et al*., 1974). Teo and Nishimoto (1973) increased the tuber sprouting by treating them with 100 ppm w/w of benzyl adenine (BA).

Tuber population of purple nutsedge in soil

Purple nutsedge tuber populations of 1,100 to 8,700/m^2 have been reported from many parts of the world (Baker, 1964; Hammerton, 1974; Hauser, 1962; Tripathi, 1969). Cultivated soils in India contained larger number of smaller tubers than uncultivated soils (Rao, 1968). Tubers in the uncultivated soils contained more starch than those in cultivated soils.

Soil type can influence tuber production of purple nutsedge (Ranade and Burns, 1925). In India, purple nutsedge grown in loose sand/clay soils produced fewer and large dormant tubers on deeply penetrating rhizomes whereas those grown in hard drying soils produced small tubers on a compact rhizome system.

The upper 15 cm of soil carried a greater percentage of tubers (Andrews, 1940; Rao 1968, Smith and Mayton 1942). Penetration of tubers to deeper layers occurred in sandy soils than in clay soils (Andrews, 1940; Smith and Mayton, 1942).

Crop yield losses due to purple nutsedge

Different crop species have different degrees of yield losses due to interference by purple nutsedge (Keeley and Thullen, 1978; William and Warren, 1975a). In Brazil, 600 to 1,600 purple nutsedge plants/m^2 reduced crop yields as follows: Garlic (*Allium sativum* L.) 89%, okra (*Hibiscus esculentus* L.) 62%, 'Kuroda' and 'Nantes' cultivars of carrot (*Daucus carota* L.) 39 and 50% respectively, green bean (*Phaseolus vulgaris* L.) 41%, cucumber (*Cucumis sativa* L.) 43%, cabbage (*Brassica oleracea* L.) 35% and tomato (*Lycopersicon esculentum* Mill.) 53% (William and Warren, 1975a).

In El Salvador, 700 plants/m^2 of purple nutsedge reduced corn (*Zea mays* L.) yield by 43% (Chase and Appleby, 1979b). In the Philippines, increased purple nutsedge density reduced the yield of rice (*Oryza sativa* L.) (Okafor and De Datta, 1976). Yield reductions of 32, 36 and 39% in rice occurred at 0, 40 and 120 kg/ha of N fertilizer, respectively as a result of purple nutsedge inteference.

Control of purple nutsedge

Early attempts to control or eradicate purple nutsedge were mainly by repeated plowing followed by desiccation of the tubers (Ranade and Burns, 1925; Sinha and Thakur, 1967; Smith and Mayton 1938, 1942). Desiccation of purple nutsedge tubers to 13% moisture or below killed them (Ranade and Burns, 1925; Tripathi, 1968). Ranade and Burns (1925) in India observed that an 8 day exposure to sun after plowing killed purple nutsedge tubers. Repeated plowing every 3 weeks or less over two growing seasons eradicated purple nutsedge in Alabama (Smith and Mayton, 1942).

Since their discovery, herbicides have been used to control purple nutsedge. Some herbicides that were effective in controlling purple nutsedge were; 2,4-D ((2,4-dichlorophenoxy)acetic acid) (Burgis, 1969), bentazon (3-isopropyl-1H-2,1,3-benzothidiazine-4(3H) -one,2,2-dioxine) (Thompson and Daniel, 1974), EPTC (S-ethyl dipropylthiocarbamate) (Antognini et al., 1959; William et al., 1976), amitrole (3-amino-s-triazole) (Hauser, 1963), MSMA (monosodium methane-arsonate) (Hamilton, 1971), nitrofen (2,4-dichlorophenyl 4-nitrophenylether) (William and Warren 1975b) and glyphosate (N-(phosphonomethyl)glycine) (Baird et al., 1971).

Purple nutsedge tubers exhibit apical dominance (Muzik and Cruzado, 1950; Ranade and Burns, 1925; Smith and Fick, 1942). Apical dominance inhibits sprouting of buds below the terminal bud of a tuber or sprouting of tubers basipetal to a tuber. Breakage of the interconnected tubers releases the apical dominance and makes it possible for otherwise dormant tubers to sprout (Muzik and Cruzado, 1950; Ranade and Burns, 1925). Those working with herbicides utilized this principle in eradication programs of purple nutsedge by applying herbicides at different growth stages of this weed after repeated plowing.

Some of the herbicides tested with repeated plowing were: 2,4-D (Hauser, 1963; Parker et al., 1969; Standifer, 1974), amitrole (Ray and Wilcox, 1969), MSMA (Hamilton, 1971; Keeley and Thullen, 1971) and glyphosate (Doll and Piedrahita, 1982; Klosterboer, 1974; Zandstra *et al.*, 1974).

Repeated plowing followed by desiccation and repeated application of herbicides, are expensive for the user and make the land unavailable for crops during the process.

Use of glyphsoate for control of purple nutsedge

Glyphosate, introduced in 1971, is a non-selective herbicide with post-emergence activity and no soil residual action (Baird *et al.*, 1971). At 2.0 and 4.0 kg/ha glyphosate gave effective control of purple nutsedge (Chase and Appleby, 1979b; Magambo and Terry, 1973; Toth and Smith, 1979; Zandstra *et al.*, 1974). However, eradication of this weed was not achieved in spite of repeated applications at different rates and at different growth stages of the plant (Klosterboer, 1974; Standifer, 1980; Zandstra *et al.*, 1974).

Field applications of less than 2.0 kg/ha glyphosate have reduced purple nutsedge stands (Doll and Piedrahita, 1982; Toth and Smith, 1979). Doll and Piedrahita (1982) obtained a 72% reduction of purple nutsedge emergence after three applications of glyphosate at 1.5 kg/ha. During the rainy season, 1.0, 2.0 and 3.0 kg/ha were equally effective, however, 1.0 kg/ha was not sufficient during the dry season. Toth and Smith (1979) reduced purple nutsedge population by 35 to 65% with 0.5 kg/ha glyphosate and 35 to 87% with 1.0 kg/ha.

Factors affecting glyphosate activity in purple nutsedge

High relative humidity (Chase and Appleby, 1979a; Wills, 1975), increased shade (Moosavi-Nia and Dore, 1979), increased foliar coverage (Doll and Piedrahita, 1982), and absence of soil moisture stress (Moosavi-Nia and Dore, 1979) increased the toxicity of glyphosate to purple nutsedge. Suwunnamek and Parker (1975) obtained increased activity of glyphosate on purple nutsedge by mixing ammonium sulfate at 1.2 kg/ha with glyphosate applied at 0.2 and 0.4 kg/ha. However, field applications did not support the results of the greenhouse experiments.

Wills and McWhorter (1985) observed that addition of ammonium chloride increased toxicity of glyphosate to purple nutsedge. Salts of monovalent cations increased glyphosate toxicity and salts of divalent cations caused no change in glyphosate toxicity to purple nutsedge. Ammonium chloride increased translocation of glyphosate in purple nutsedge.

Summer applications of glyphosate gave better control of purple nutsedge than spring applications (Cools and Locascio, 1977; Toth and Smith, 1979). Poor control during spring was attributed to the unsprouted tubers present during this time (Cools and Locascio, 1977).

Effects of glyphosate on purple nutsedge tuber sprouting

Glyphosate reduced the sprouting of purple nutsedge tubers (Chase and Appleby, 1979b; Doll and Piedrahita, 1982; Magambo and Terry, 1973; Toth and Smith, 1979). At 0.5, 1.0 and 2.0 kg/ha the reductions in tuber sprouting were, 21, 36, and 89% respectively when sampled 14 days after application (Doll and Piedrahita, 1982). However, the reduction in sprouting was 12, 18 and 76% for the three rates respectively 28 days after application. At 56 days the reduction in sprouting was 11, 11 and 54% for the three rates respectively. Most tubers that did not sprout desiccated in 2 months, however, some took as long as 15 months to desiccate.

Effect of low levels of glyphosate on plants

Glyphosate is not metabolized in many plants, including purple nutsedge (Sandberg et al., 1980; Wyrill and Burnside, 1976; Zandstra and Nishimoto, 1977). Low levels of glyphosate reduced the height, fresh weight, and dry weight of jointed goatgrass (*Aegilops cylindrica* Host), quackgrass (*Agropyron repens* L.), sorghum (*Sorghum bicolor* L.), and wheat (*Triticum aestivum* L.) (Baur et al., 1977; Young et al., 1984). Glyphosate at 0.6 kg/ha reduced the height of downy brome (*Bromus tectorum* L.), wheat, jointed goatgrass and common rye (*Secale cereale* L.) by 3, 7, 5 and 7% respectively (Young et al., 1984). The dry weight reductions were, 14, 12, 18 and 23% respectively, for the four species. Glyphosate at 5.6 ug/plant and more reduced the height and weight of sorghum and wheat (Baur et al., 1977). The reduction in fresh weight was greatest at the optimum temperature for growth of each species.

The reduction in fresh weight or height in plants treated with low levels of glyphosate sometimes occurred after an initial increase as found in jointed goatgrass, quackgrass and sorghum (Baur et al., 1977; Coupland and Caseley, 1975; Young et al., 1984). Glyphosate at 0.3 kg/ha increased fresh weight of quackgrass by 62% (Coupland and Caseley, 1975). A 23% increase in fresh weight occurred in sorghum with 2.8 ug/plant of glyphosate (Baur et al., 1977). Jointed goatgrass height increased by 9% with soil applied glyphosate at 0.6 kg/ha (Young et al., 1984).

Low levels of glyphosate released the apical dominance and caused basal bud development and tillering in sorghum, quackgrass, and wheat (Baur *et al*., 1977; Coupland and Caseley, 1975). With 0.3 kg/ha glyphosate, quackgrass produced 49 basal buds compared to 16 in the untreated control (Coupland and Caseley, 1975). With glyphosate at 5.6 ug/plant, 74% of wheat plants produced auxiliary buds whereas only 5% of the untreated plants had auxiliary buds (Baur *et al*., 1977). In sorghum, 11.2 ug/plant of glyphosate caused 65% of the plants to produce auxiliary buds with none producing buds without glyphosate.

In yellow nutsedge (*Cyperus esculentus* L.), 0.5 kg/ha glyphosate increased tuber production (Linscott and Hagin, 1973). Tubers of 30-cm tall yellow nutsedge treated with 3.0 kg/ha glyphosate produced an increased number of shoots when planted (Boldt and Sweet, 1974).

Translocation and accumulation of glyphosate in plants

Glyphosate accumulated mainly in actively growing meristematic regions of plants (Claus and Behrens, 1976; Devine and Bandeen, 1983; Haderlie *et al*., 1976; Sandberg *et al*., 1980; Smid and Hiller, 1981; Wyrill and Burnside, 1976; Zandstra and Nishimoto, 1977). In 6-week-old purple nutsedge, glyphosate accumulated mainly in newly developing tubers and leaves (Zandstra and Nishimoto, 1977). However, the accumulated glyphosate in morningglory (*Ipomoea purpurea* L.) and quackgrass was re-translocated to artificially created sinks (Devine and Bandeen, 1983; Dewey and Appleby, 1983).

Both apoplastic and symplastic translocation of glyphosate occurred in quackgrass and morningglory (Devine and Bandeen, 1983; Dewey and Appleby, 1983; Klevorn and Wyse, 1985). Basipetal translocation was primarily via phloem and acropetal translocation via apoplast. However, some diffusion of glyphosate between apoplast and symplast occurred. Translocation of glyphosate closely followed the pathway and rate of photoassimilate in Canada thistle (Cirsium arvense L.), morningglory and quackgrass (Devine and Bandeen, 1983; Dewey and Appleby, 1983; Klevorn and Wyse, 1984; McAllister and Haderlie, 1985).

Klevorn and Wyse (1984) reported that girdling the culms of quackgrass shoots increased the accumulated glyphosate in rhizomes. Removal of rhizome buds or apices of rhizomes did not affect the translocation or accumulation of glyphosate. Klevorn and Wyse (1984) concluded that the rhizome of quackgrass is a sink for glyphosate independent of the presence or absence of buds or apices.

Increased moisture stress decreased the absorption and translocation of glyphosate in quackgrass (Klevorn and Wyse, 1984) and milkweed (Asclepias syriaca L.) (Waldecker and Wyse, 1985). Changes in day length from 13 h (for vegetative growth) to 15 h (for flowering) did not alter glyphosate translocation or distribution in Canada thistle (McAllister and Haderlie, 1985). An increase in temperature from 7 to 12 and 17 C increased the translocation and accumulation of ^{14}C activity in the rhizomes of quackgrass following application of ^{14}C-glyphosate (Klevorn and Wyse, 1984).

Management of purple nutsedge in crops

Purple nutsedge is a poor competitor under shade (Ranade and Burns, 1925). Purple nutsedge has the C-4 photosynthetic pathway (William and Warren, 1975a; Wills, 1975) and hence it grows most rapidly in full sun. Patterson (1982) showed that decreasing light from full sun to 85% shade decreased the number of tubers from 115 to 26/plant in 62 days. Tuber weight decreased from 0.16 g/tuber to 0.07 g/tuber in the two light levels respectively. Clearly it seems that shade reduced or prevented accumulation of food in the tubers. This may be why purple nutsedge is a poor competitor in shade. However, 30 days of exposure to full sun after 30 days of 85% shade increased the tuber number to 82/plant and the average weight of a tuber to 0.19 g/tuber (Patterson, 1982). Therefore, purple nutsedge seems to have a remarkable ability to recover from ill-effects caused by shade.

Crops competitive with purple nutsedge reduced the yield losses due to purple nutsedge (Keeley and Thullen, 1978; William and Warren, 1975a). Crops that were competitive with purple nutsedge were green bean (William and Warren, 1975a), corn, potato (*Solanum tuberosum* L.), safflower (*Carthamus tinctorius* L.) and alfalfa (*Medicago sativa* L.) after cutting (Keeley and Thullen, 1978). In Israel, cotton (*Gossypium hirsutum* L.) planted 3 weeks prior to purple nutsedge reduced the fresh weight of this weed by 68% (Horowitz, 1972). In Brazil, nitrofen at 1.0 to 4.0 kg ai/ha reduced purple nutsedge stand by 56 to 65% and increased the yield of carrot by 44% (William and Warren, 1975b).

EPTC at 2.0 kg/ha gave satisfactory control of purple nutsedge during the dry season in Brazil (William *et al.*, 1976). During the rainy season, the rate of EPTC for comparable control of purple nutsedge was 4.0 kg/ha. However, due to toxicity of EPTC during both seasons, planting of okra, cucumber, red beet (*Beta vulgaris* L.), carrot and lettuce (_Lactuca sativa_ L.) had to be delayed from 4 days to 3 weeks.

No information on the long-term management of purple nutsedge in crops is available. However, some work has been done with yellow nutsedge control with glyphosate (Keeley _et al_., 1974; Standifer, 1980).

In a 2-year soybean (_Glycine max_ L.)-pepper (_Solanum annum_ L.) rotation, glyphosate applied in October and April at 1.1, 2.2 and 4.5 kg/ha reduced the yellow nutsedge tuber population to 1% of the control within 1 year (Standifer, 1980). In plots fallowed with glyphosate, Keeley _et al_. (1979) reduced yellow nutsedge population by 91 to 98% in 2 years. In alfalfa, glyphosate at 2.0 kg/ha applied prior to planting gave good control of yellow nutsedge during the establishment period of the crop (Taranawich and Linscott, 1975). A combination of glyphosate and discing resulted in a better control of yellow nutsedge.

CHAPTER III

EFFECT OF FOLIAR APPLICATION OF GLYPHOSATE ON SPROUTING OF PURPLE NUTSEDGE TUBERS

Abstract. Sprouting of basal bulbs and tubers from different locations of the rhizome of purple nutsedge (*Cyperus rotundus* L.) was investigated with samples taken 3 weeks after field application of glyphosate (*N*-(phosphonomethyl)glycine) at 1.0 and 2.0 kg ae/ha. The experiment was conducted three times in 1984 (March, June and October) and once in March 1985.

Glyphosate decreased sprouting of tubers more in June and October than in March. Most affected were the developing tubers, with 29% sprouting at 1.0 and 8.0% at 2.0 kg/ha glyphosate in the four experiments. Least affected were the parent tubers that were in chains of two with 71% sprouting at 1.0 and 52% sprouting at 2.0 kg/ha glyphosate. Singly occurring parent tubers had 53% sprouting with 1.0 and 32% sprouting with 2.0 kg/ha glyphosate. Basal bulbs responded similarly to parent tuber chains of two with 68% sprouting at 1.0 and 46% sprouting at 2.0 kg/ha glyphosate.

Basal bulbs and newly developing tubers attached to basal bulbs were sampled after different times of exposure of purple nutsedge to glyphosate. Sprouting of newly developing tubers was reduced within 12 h at 2.0 kg/ha and 2 days at 1.0 kg/ha glyphosate. With 2.0 kg/ha glyphosate, basal bulbs were unaffected for up to 16 days exposure in March, but a 60% reduction in sprouting occurred after 8 days of exposure in June.

Introduction

Purple nutsedge (*Cyperus rotundus* L.) is the most common weed in tropical crops (Holm *et al.*, 1977). It propagates by tubers and basal bulbs that occur in an underground rhizome system (Ranade and Burns, 1925).

Basal bulbs are corms that bear leaves and inflorescences (Ranade and Burns, 1925). Any underground propagule that does not have leaves is a tuber. Every sprouting parent tuber produces a basal bulb. Therefore, in a purple nutsedge stand, the parent population of tubers does not have direct aerial connections. The basal bulbs produce new basal bulbs and tubers in a developing rhizome system.

Glyphosate (*N*-(phosphonomethyl)glycine) is a herbicide that is toxic to purple nutsedge (Baird *et al.*, 1971). However, repeated applications of glyphosate did not eradicate this weed (Chase and Appleby, 1979b; Klosterboer, 1974; Martinez and Pulver, 1975; Wilfret and Burgis, 1976; Zandstra *et al.*, 1974).

Glyphosate accumulates differentially in plants with most accumulating in growing meristematic tissues (Claus and Behrens, 1976; Devine and Bandeen, 1983; Haderlie *et al.*, 1976; Sandberg *et al.*; 1980; Smid and Hiller, 1981; Wyrill and Burnside, 1976, Zandstra and Nishimoto, 1977). In purple nutsedge, 6 week old plants accumulated ^{14}C in developing tubers and leaves following an application of ^{14}C-glyphosate (Zandstra and Nishimoto, 1977). Therefore, differential effects of glyphosate might be expected on purple nutsedge tubers at different stages of meristematic activity.

This study was conducted to determine the effects of the differential accumulation of glyphosate in purple nutsedge on sprouting of tubers located at different positions of the rhizome system.

Materials and Methods

All experiments were conducted at the Waimanalo Research Station, Oahu, Hawaii. Fields with purple nutsedge were rotovated to a depth of 15 cm and leveled. This was followed by twice weekly irrigation (1.5 to 2.0 cm at a time) for 9 weeks. Control of other weeds was achieved by spraying atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)*s*-triazine) at 2.0 kg ai/ha followed by irrigation at the beginning of each experiment. This was followed by handweeding when necessary. Fertilizer as 10:30:10 $N:P_2O_5:K_2O$ was applied at 1,000 kg/ha (100:130:80 kg N:P:K/ha) rate in split applications at the beginning and 4 weeks after initiation of each experiment.

Glyphosate was applied at 1.0 and 2.0 kg ae/ha in 375 liters/ha over 6 week old purple nutsedge, in plots of 7.2 m by 2.0 m. An unsprayed area served as the control.

Experiment 1. Effect of foliar applied glyphosate on the sprouting of tubers from different locations of the tuber system.

Three weeks after the application of glyphosate, 10 each of basal bulbs, single parent-tubers, two-tuber parent chains and newly developing tubers attached to basal bulbs were dug from each treatment. Five such sets were taken in a completely randomized pattern.

The tubers were washed and sprouted in petri dishes for 3 weeks at 23 C. After 3 weeks, they were treated with 10 ml of 100 ppm w/w benzyl adenine (BA). Counts of sprouted tubers were taken at weekly intervals for 10 weeks.

The experiment was conducted three times in 1984 (March, June and October) and once in March 1985.

During the March 1985 experiment, 5 tubers from each type that sprouted before adding BA were planted in 15 cm pots in a 2:2:1 ratio of vermiculite/perlite/peat moss. Fertilizer as 14:14:14 osmocote (3 month release rate) was applied to these pots at 2,000 kg/ha. They were grown outdoors at Magoon facility of the University of Hawaii with irrigation twice a day. Six weeks later, the top and underground parts were harvested and dried at 65 C for 7 days. The tubers were counted and the leaves and tubers (except the planted tuber) were weighed.

Experiment 2. Effect of time of exposure of purple nutsedge to glyphosate on sprouting of basal bulbs and developing tubers attached to them.

Ten basal bulbs and 10 newly developing tubers attached to the basal bulbs were sampled at 0, 3, 6, and 12 h, and at 1, 2, 4, 8 and 16 days after spraying glyphosate. Five samples of each type of tuber were taken at each time. They were washed and sprouted as described in experiment 1. The sprouting counts were taken at weekly intervals for 10 weeks. The experiment was conducted twice in 1984 (March and June) and once in March 1985.

Results and Discussion

Sprouting of tubers from different locations of the tuber system after glyphosate application

Newly developing tubers were the most affected by glyphosate (Figure 3.1). An increase in applied glyphosate from 1.0 to 2.0 kg/ha decreased the sprouting of these tubers except in October 1984. In March 1985 glyphosate at 1.0 kg/ha did not decrease the sprouting of these tubers.

Least affected by glyphosate were the basal bulbs and tubers from 2-tuber parent chains and they showed the least damage in March (Figure 3.1). In fact, in March 1985, the use of 2.0 kg/ha glyphosate did not reduce the sprouting of basal bulbs and tubers from 2-tuber parent chains. In October, the sprouting of basal bulbs and tubers from 2-tuber parent chains was reduced with increased glyphosate rate. Two-tuber parent chains were not sampled in June.

Glyphosate reduced the sprouting of single parent-tubers (Figure 3.1). The reduction in sprouting with an increase in glyphosate from 1.0 to 2.0 kg/ha was not significant in March or October 1984. There was less sprouting of single parent tubers at 2.0 kg/ha glyphosate in March 1985 than in March 1984.

The sprouting pattern of tubers after application of glyphosate is directly related to the known accumulation pattern of glyphosate in purple nutsedge described by Zandstra and Nishimoto (1977). According to them, the most accumulation of glyphosate in 6-week old purple nutsedge was in newly developing tubers.

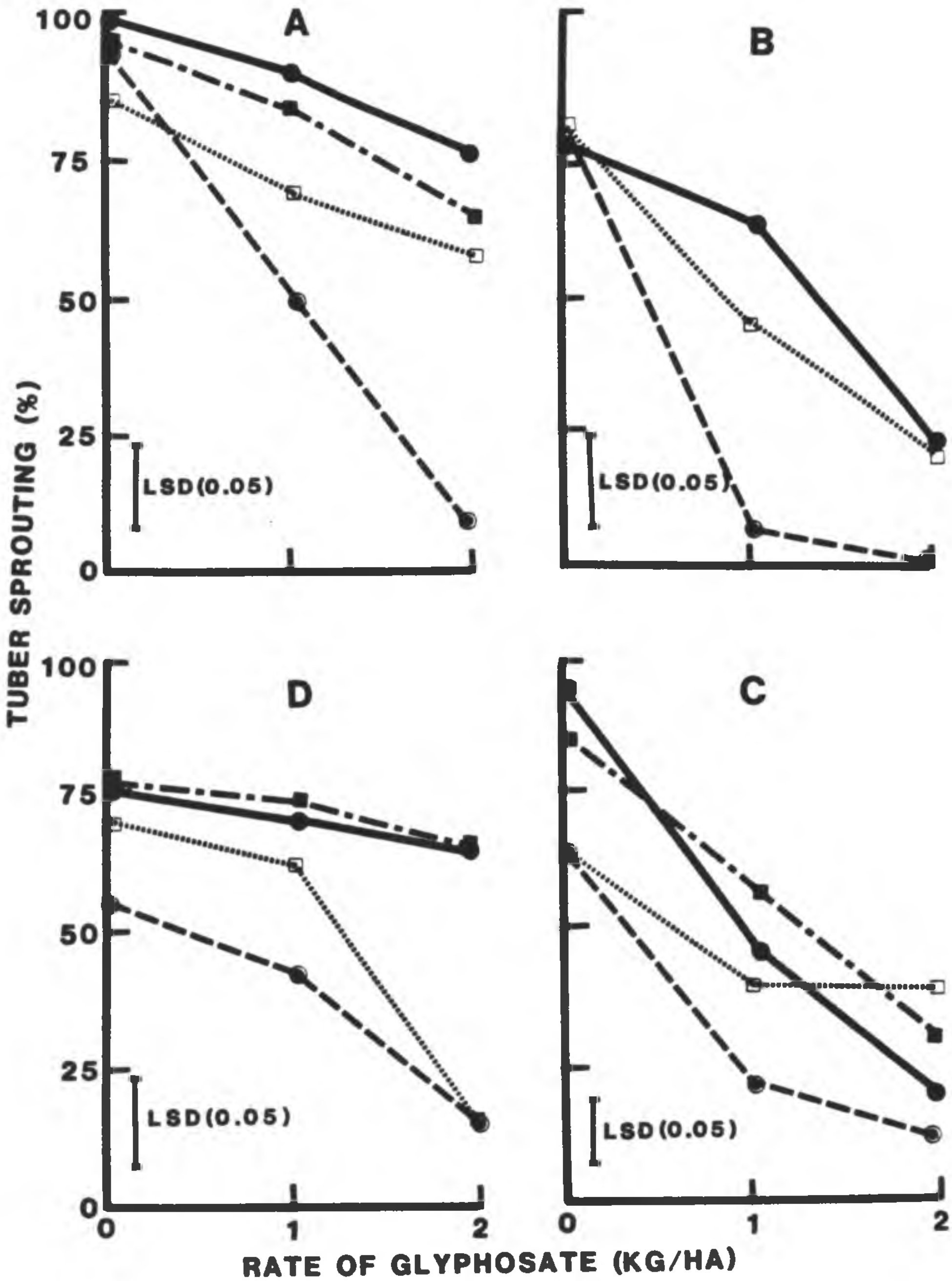

Figure 3.1. Sprouting of purple nutsedge basal bulbs (———), newly developing tubers (— — —), singly occurring parent tubers (··········) and tubers from 2-tuber parent chains (— · — ·) in March 1984 (A), June 1984 (B), October 1984 (C) and March 1985 (D), after treating with glyphosate. (Average of five replicates).

The sprouted tubers of treated plants, when planted outdoors, yielded plants with different dry weight and tuber numbers (Table 3.1). Those from two-tuber chains produced the greatest leaf dry weight at 1.0 kg/ha glyphosate. However, at 2.0 kg/ha, the leaf dry weight declined to 0.76 g.

Glyphosate, at very low levels increased height and fresh weight of jointed goatgrass (*Aegilops cylindrica* Host) and sorghum (*Sorghum bicolor* L.) (Baur *et al*., 1977; Young *et al*., 1984). However, further increases in glyphosate level decreased both height and dry weight of these plants.

The increased weight of leaves obtained from plants of two-tuber chains at 1.0 kg/ha and a decrease in weight at 2.0 kg/ha (Table 3.1) suggests that the sprouted tubers contained glyphosate. The decrease in dry weight at 2.0 kg/ha was presumably because these tubers contained more glyphosate than at the 1.0 kg/ha rate of application.

Although less pronounced, similar trends occurred with tuber dry weight and tuber number (Table 3.1). The most affected were the plants from single parent tubers at 2.0 kg/ha glyphosate.

Glyphosate is not metabolized once inside a plant (Sandberg *et al*., 1980; Wyrill and Burnside, 1976; Zandstra and Nishimoto, 1977). Hence, these results suggest that the tested tubers indeed contained glyphosate and sprouted nonetheless, with the residual herbicide continuing to affect the first generation of plants.

Table 3.1. Growth of 6 week old purple nutsedge from tubers of glyphosate treated and untreated plants.[xy]

Tuber type	Dry weight Leaf	Dry weight Tuber	Number of tubers
	--------(g)--------		(tubers/plant)
	----------control----------		
Basal bulbs	0.56bcd	0.76bcd	9.0b
Single parent tubers	0.64bcd	1.28abc	10.5ab
Two tuber parent chains	0.80bc	1.52ab	12.3ab
	---glyphosate 1.0 kg/ha----		
Basal bulbs	0.84b	1.02bcd	12.2ab
Single parent tubers	0.84b	1.45ab	12.1ab
Two tuber parent chains	1.40a	2.01a	16.6a
	---glyphosate 2.0 kg/ha----		
Basal bulbs	0.30cd	0.54cd	6.2bc
Single parent tubers	0.12d	0.22d	1.5c
Two tuber parent chains	0.76bc	1.38ab	10.6ab

[x] Average of five replicates.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

Glyphosate inhibited sprouting of parent tubers and basal bulbs more in June and October than in March (Figure 3.1). Glyphosate translocation closely followed the path of assimilates (Devine and Bandeen, 1983; Dewey and Appleby, 1983; Klevorn and Wyse, 1984). Waimanalo had high air temperatures during the June and October exposure periods (Table 3.2). The rate of photosynthesis and assimilate flow should have been greater during these two months than during March. Therefore, more glyphosate could have been translocated to the tubers during June and September than during March.

Table 3.2. Mean daily minimum and maximum temperature at Waimanalo during exposure period of purple nutsedge to glyphosate.

	Mean daily temperature	
Month	Minimum	Maximum
	------C------	
March 1984	21	27
June 1984	23	31
October 1984	22	31
March 1985	20	26

Conversely the greater activity of glyphosate during warm weather could also kill the tubers that accumulate glyphosate most, namely the newly developing tubers. Once the newly developing tubers are killed, the assimilates and glyphosate which follows the path of assimilates, may be diverted to other possible sinks. In purple nutsedge, these are the basal bulbs and parent tubers.

Glyphosate caused inhibition of tuber sprouting in purple and yellow nutsedge (Cyperus esculentus L.) (Appleby and Paller, 1978; Doll and Piedrahita, 1982; Magambo and Terry, 1973; Toth and Smith, 1979). Doll and Piedrahita (1982) found that the tubers that did not sprout following a glyphosate application eventually died. Some tubers from treated plants in this study sprouted, but showed the presence of glyphosate by changes in the growth of the resulting plants. These tubers may have received less glyphosate than was needed to cause dormancy. Hence, if translocation of glyphosate to all tubers is increased to the level that will prevent sprouting, a better control of this weed can be expected. Use of glyphosate during hot weather seems to result in better translocation of the herbicide to all tubers.

Effect of period of exposure of purple nutsedge to glyphosate on sprouting of basal bulbs and newly developing tubers attached to them

Sprouting of newly developing tubers began to decline 12 h after exposure to glyphosate at 2.0 kg/ha (Figures 3.2-3.4). Sprouting declined more with increased exposure time to glyphosate. However, the basal bulbs, through which glyphosate was translocated, showed some reduction in sprouting after 8 to 16 days of glyphosate exposure. In March 1985, the reduction in sprouting was not significant even at 16 days of exposure. In March 1984, a significant reduction in sprouting occurred only at 16 days of exposure. A substantial reduction in sprouting of basal bulbs

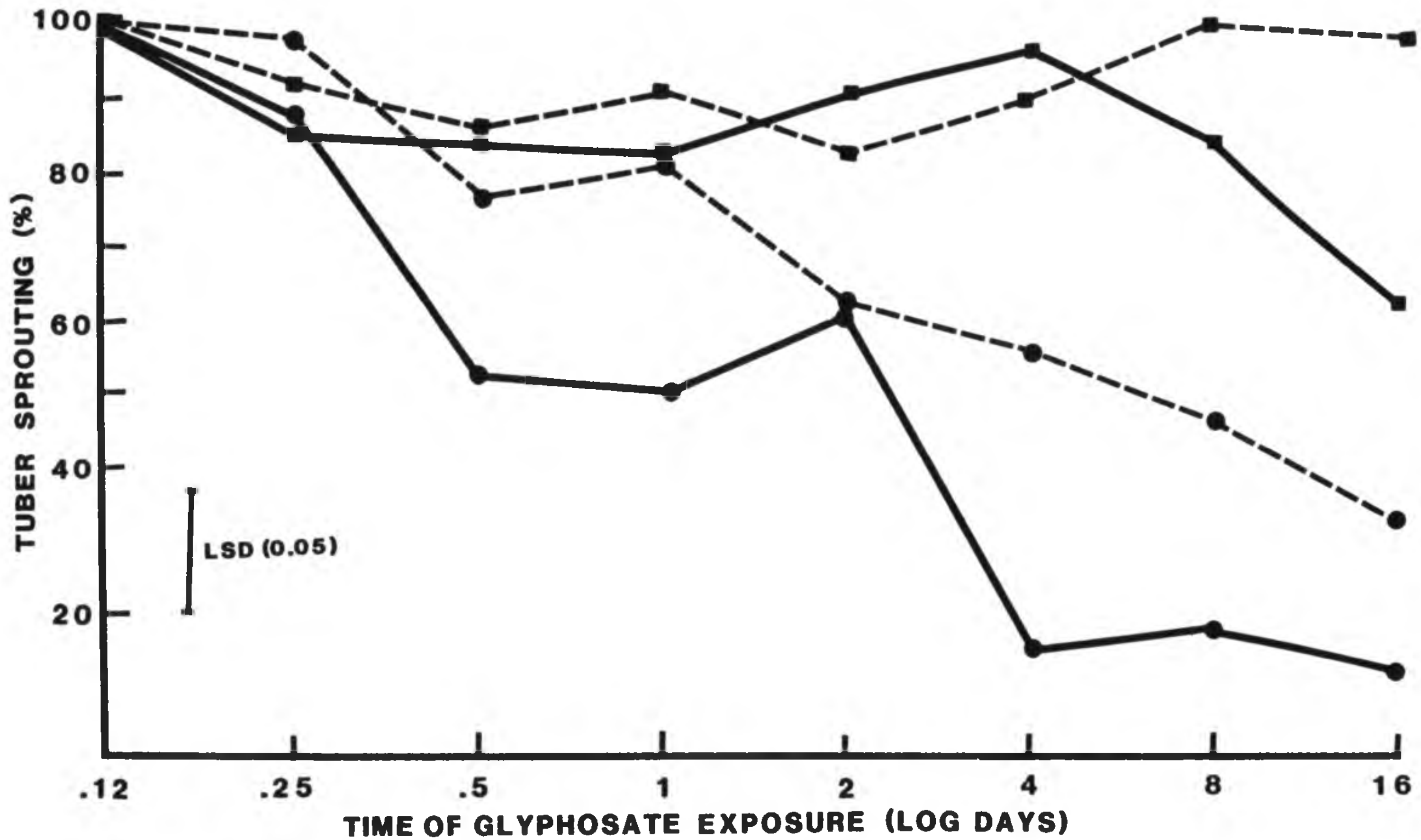

Figure 3.2. Sprouting of basal bulbs (■) and newly developing tubers (●) of purple nutsedge after different times of exposure to glyphosate at 1.0 kg/ha (– – –) and 2.0 kg/ha (———) in March 1984. (Average of five replicates).

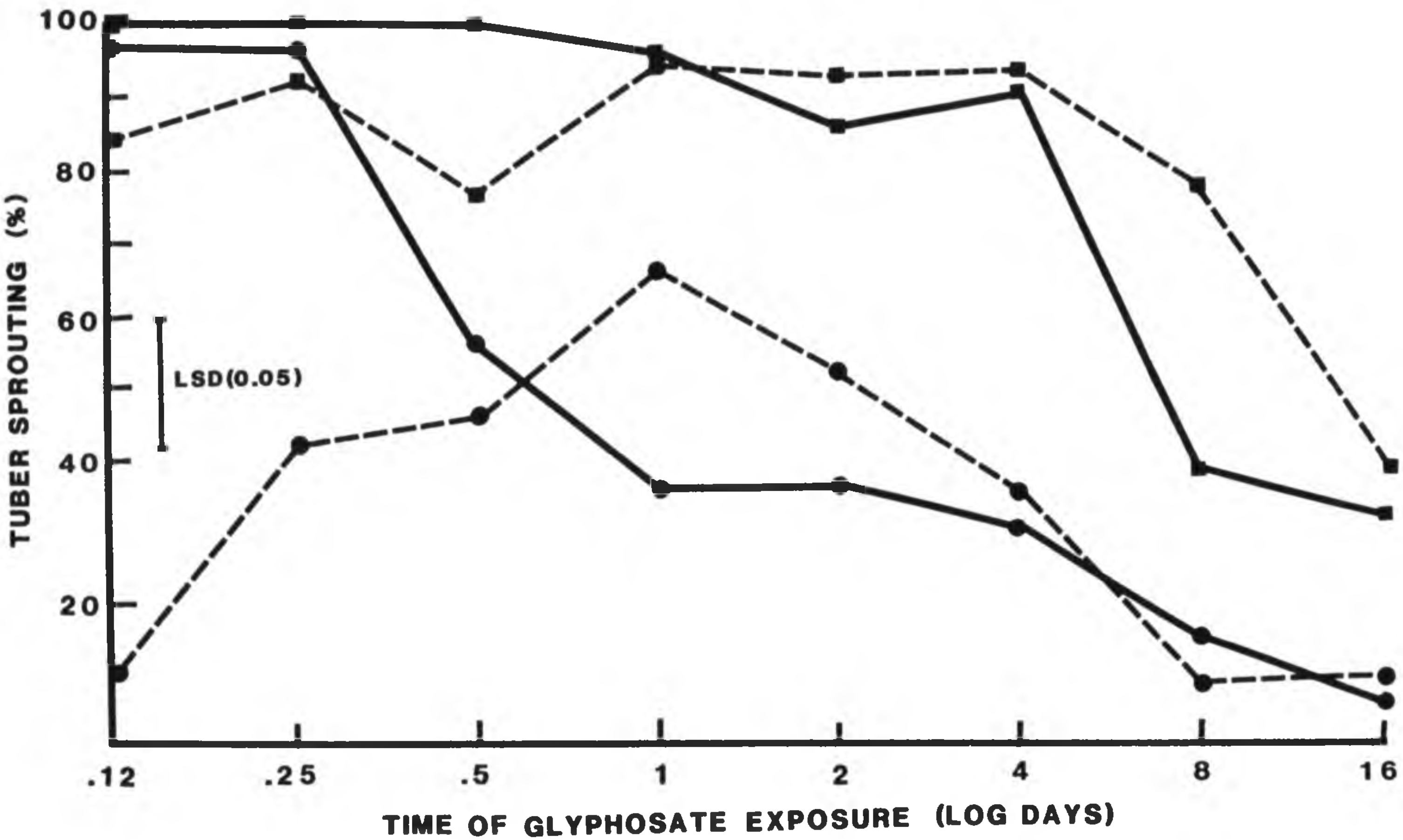

Figure 3.3. Sprouting of basal bulbs (■) and newly developing tubers (●) of purple nutsedge after different times of exposure to glyphosate at 1.0 kg/ha (— — —) and 2.0 kg/ha (———) in June 1984. (Average of five replicates).

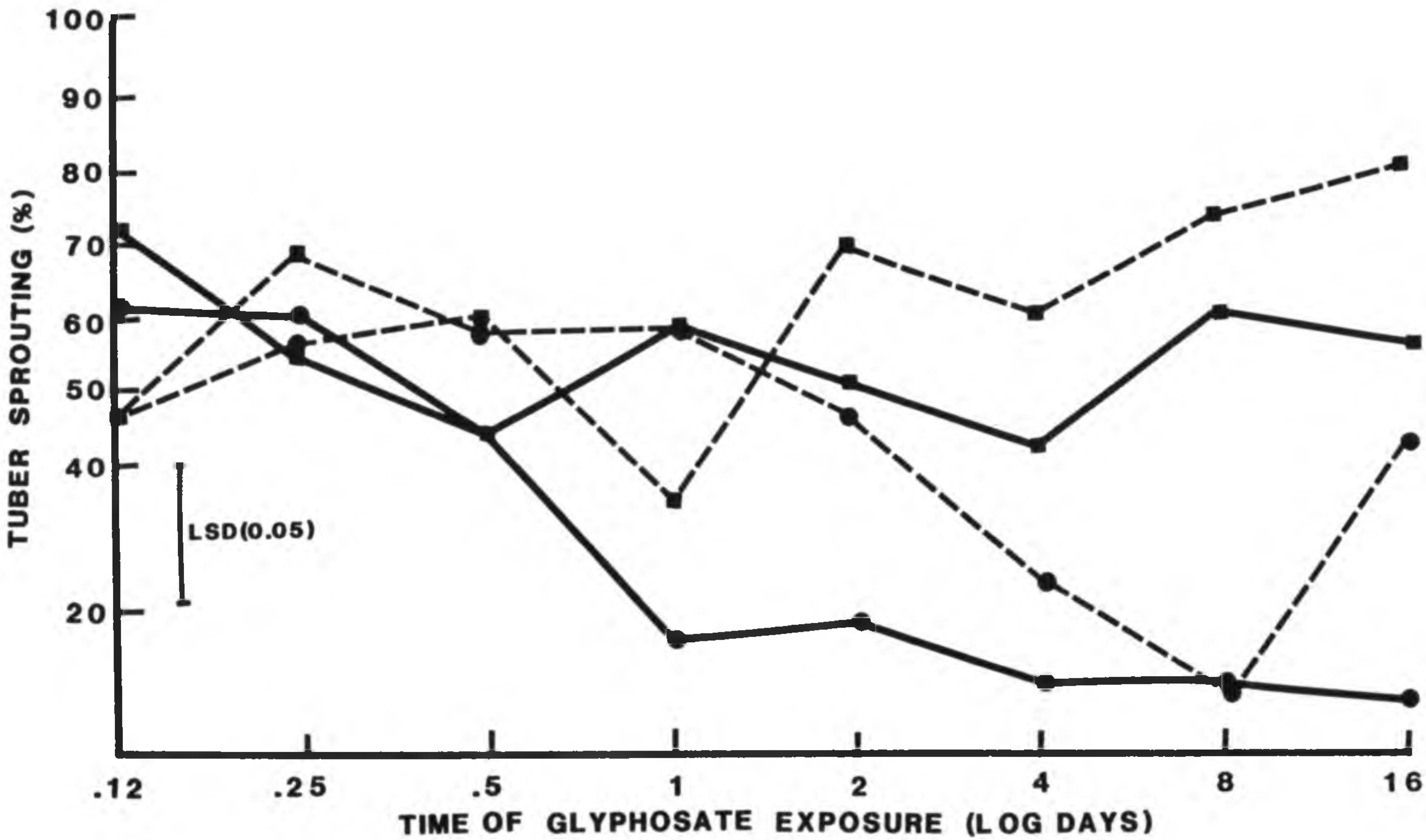

Figure 3.4. Sprouting of basal bulbs (■) and newly developing tubers (●) of purple nutsedge after different times of exposure to glyphosate at 1.0 kg/ha (– – –) and 2.0 kg/ha (———) in March 1985. (Average of five replicates).

occurred during the June treatment 8 days after glyphosate exposure period. These results agree with those of Experiment 1, in which reduction of sprouting of basal bulbs was least in March (Figure 3.1).

At 1.0 kg/ha of glyphosate, a period of 2 to 4 days of exposure was required to reduce sprouting of newly developing tubers (Figures 3.2-3.4). This is consistent with the observations of Doll and Piedrahita (1982) that 48 h of exposure to field application of glyphosate at 1.0 kg/ha caused a reduction in purple nutsedge tuber sprouting. The exposure needed for a similar reduction of sprouting at 2.0 kg/ha glyphosate was 24 h.

It was observed that addition of BA 3 weeks after incubation did not increase the sprouting of purple nutsedge tubers. Most sprouting of the tubers occurred during first 2 weeks of incubation.

Conclusion

Field applied glyphosate at 1.0 and 2.0 kg/ha resulted in differential sprouting of basal bulbs and tubers from different parts of the plant. The least sprouted were the newly developing tubers. The least affected were the basal bulbs and chains of two tubers. In addition, the response to glyphosate showed a seasonal variation with greater reduction in tuber sprouting in June and October than in March.

Tubers and basal bulbs of purple nutsedge which sprouted following glyphosate application were capable of producing plants and new tubers. However, growth was suppressed in plants derived from tubers of plants treated with 2.0 kg/ha glyphosate. At 1.0 kg/ha, glyphosate treated plants from tubers of two-tuber chains had greater foliage dry weights than the controls.

Glyphosate at 2.0 kg/ha reduced sprouting of newly developing tubers after 12 h exposure. However, a reduction of sprouting in basal bulbs occurred only after 8 days exposure in June and October. In March there was a minimal effect on basal bulbs even at 2.0 kg/ha rate. As a result, complete kill of all tubers was never achieved by application of glyphosate at any time. Therefore, eradicaton of purple nutsedge by use of glyphosate alone at the 2.0 kg/ha rate seems impossible. However, better control of this weed with glyphosate could be achieved during warmer periods of the year.

Since glyphosate can not eradicate purple nutsedge, use of the 2.0 kg/ha rate of glyphosate may be futile. Instead the reduction of tuber sprouting at 1.0 kg/ha may be combined with crop management strategies for an economical crop production.

CHAPTER IV

DISTRIBUTION OF PURPLE NUTSEDGE TUBERS IN SOIL AND ITS GROWTH PATTERN

Abstract. The upper 30 cm of a field infested with purple nutsedge (*Cyperus rotundus* L.) contained 4,900 to 5,100 tubers/m^2 6 weeks after rotovation and irrigation. Tuber population in the upper 4, 8, 12 and 16 cm was 45, 79, 95 and 99% respectively. Deeper layers of soil contained larger tubers with higher percent dry matter than shallow layers. Of the total tubers found, 51% were from the parent population. Fifteen percent of the tubers were single unsprouted tubers. Chains of up to eight tubers from the parent population were found. Tubers from the parent population weighed more than those from the new population. Once a tuber established a new plant, more new rhizomes appeared from the basal bulb and the parent tuber. Appearance of new rhizomes from the parent tuber increased with planting depth.

Introduction

Purple nutsedge (*Cyperus rotundus* L.) is ranked as the world's worst weed (Holm *et al*., 1977). Native to India, it is now a problem all over the world (Holm *et al*., 1977).

Main propagative organs of purple nutsedge are corms and tubers that occur in an underground rhizomatous system (Ranade and Burns, 1925). The sprouting tuber/corm produces a negatively geotropic rhizome. The rhizome ceases elongation at the soil surface, and the apical end swells to form a corm which was referred to as a basal bulb by Ranade and Burns (1925). The basal bulb produces leaves and inflorescences. Underground, it produces horizontally growing rhizomes which may, in turn, give rise to more basal bulbs or to 'dormant tubers' or tubers which do not produce aboveground parts. Rhizomes continue to form from the new basal bulbs and tubers which, in turn, produce more basal bulbs and tubers to form an underground network of basal bulbs and tubers.

Soil tuber populations between 1,100 and 8,700/m^2 have been reported from many parts of the world (Baker, 1964; Hammerton, 1968, 1974; Hauser, 1962; Tripathi, 1969). Most of the tubers occurred in the upper 15 cm of soil (Andrews, 1940; Rao, 1968; Smith and Mayton, 1940).

Ranade and Burns (1925) reported that no new rhizomes are produced from the parent tuber after initial plant establishment. However, Horowitz (1972) reported that new rhizomes arise from both parent tuber and basal bulb.

Distribution of purple nutsedge tubers in soil in Hawaii is not available. No information on frequency of different types of tubers is available from anywhere.

Experiments were conducted to determine 1) the distribution of tubers/basal bulbs in soil and 2) the extent of parent tubers that produce new rhizomes after initial plant establishment.

Materials and Methods

All experiments were conducted at the Waimanalo Research Station, Oahu, Hawaii. Fields infested with purple nutsedge were rotovated to a depth of 15 cm and leveled. Fertilizer (10:30:10 $N:P_2O_5:K_2O$) was applied at 1,000 kg/ha (100:13:80 kg N:P:K/ha) in split applications at the beginning of the experiment and 4 weeks later. The field was irrigated twice weekly with 1.5 to 2.0 cm water each time. Control of weeds other than purple nutsedge was achieved with atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine) at 2.0 kg ai/ha followed by irrigation. This was followed by handweeding when necessary.

Six weeks after the initiation of each experiment, soil blocks measuring 30 cm by 30 cm by 30 cm were dug out carefully to study the distribution and frequency of different types of tubers. Five samples were taken for each observation unless otherwise stated.

Experiments 1 and 2 were initiated in April 1984, experiment 3 in July 1984 and experiment 4 in December 1984.

In the following text, the 'tuber' will refer to any underground propagative organ unless specified as a basal bulb, dormant tuber, new tuber, or parent tuber.

Experiment 1. Distribution of tubers in the soil profile.

The soil blocks were cut horizontally into 0-4, 4-8, 8-12, 12-16 and 16-30 cm slices. These were washed and tubers were recovered. Tuber number, fresh weight and dry weight were recorded.

Experiment 2. Frequency of parent and new tubers in a 6-week old stand of purple nutsedge.

Soil blocks were soaked for 24 h and washed carefully with minimum disturbance to the rhizome systems. The rhizome systems were carefully separated.

The separation of tubers into new and old was conducted as follows: the first basal bulb of the new population was identified as the one attached to the parent tuber which is dark brown in color as opposed to the yellowish white of the new tubers. Tubers that were basipetal to the parent tuber were classified as parent tubers and the first basal bulb and those that were acropetal to this were classified as new tubers.

Parent tubers, basal bulbs and new tubers were counted. Parent tuber chains with two or more tubers attached were also counted.

Experiment 3. Growth of new rhizomes from basal bulb and the parent tuber.

Soil blocks were taken 3 weeks after initiation of the experiment. The sprouted single tubers were separated. They were classified as follows on the basis of rhizome development after initial basal bulb production.

Type A: New rhizomes formed only from the basal bulb.

Type B: New rhizomes formed both from the basal bulb and the parent tuber.

Type C: New rhizomes formed only from the parent tuber.

The number of each type was recorded. This was repeated 6 weeks after the initiation of the experiment.

Experiment 4. Effect of planting depth on development of rhizomes from the parent tuber.

In a nutsedge free area, sets of 20 purple nutsedge tubers were planted in 60 cm rows at 4, 8 and 12 cm depths. Six sets were planted in a completely randomized design. Nine weeks later, the plants were dug out without breaking the underground connections. The first ten such intact plants recovered from each row were taken for observations. Plants that contained new rhizomes from the parent tuber were counted.

Results and Discussion

Distribution of tubers in the soil profile

The highest tuber population occurred in the upper 4 cm layer of soil (Table 4.1). The number of tubers declined steadily with increasing depth. Number of tubers in soil up to 16 cm was characterized by the equation $Y = 279 - 66X$ ($r^2 = .85$) (Y = number of tubers at the soil layer X). The tuber number in the 12-16 cm layer of soil was not different from that of the 16-30 cm layer. The cumulative tuber population in the upper 4, 8, 12, and 16 cm of soil was 45, 79, 95, and 99%, respectively. These values agree with

Table 4.1. Distribution of purple nutsedge tubers in different layers of soil.[x,y]

Soil layer (cm)	Number	%	Total tuber weight Fresh	Total tuber weight Dry	Per tuber weight Fresh	Per tuber weight Dry	Percent dry matter per tuber
			----------(g)		----------		(%)
0-4	210a	45	75a	15b	.21c	.08b	22c
4-8	155b	34	78a	23a	.50b	.15ab	30b
8-12	73c	16	48b	14b	.65ab	.19a	29b
12-16	18d	4	12c	4c	.67ab	.22a	37a
16-30	5d	1	4c	1c	.80a	.22a	34ab

[x] Average of 5 replicates.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

reports that most of the tubers occurred in the upper 15 cm of soil (Andrews, 1940; Rao, 1968; Smith and Mayton, 1942).

Single tuber fresh weight and dry weight, and percentage of dry matter per tuber increased with soil depth (Table 4.1). A similar increase in per tuber weight and percent dry matter with increased depth was reported by Rao (1968).

A total tuber population of 4,900/m^2 in the upper 30 cm of soil was recorded in this experiment. The field contained 50 million tubers/ha and their fresh and dry weights were 23,300 and 6,160 kg/ha respectively.

Frequency of parent and new tubers in soil

A total of 5,080 tubers/m^2 in the upper 30 cm of soil was recorded in this experiment (Table 4.2). Of these, 51% belonged to the parent population. Of the parent population of tubers, 70% had sprouted to give basal bulbs and 30% had not sprouted. Therefore, unsprouted parent tubers with no leaves constituted 15% of the total tuber population and amounted to 750 tubers/m^2. New tubers and basal bulbs amounted to 16 and 33% of the total population respectively.

Parent tuber chains with up to 8 tubers per chain were found (Table 4.2). Of the parent population, a total of 48% of the tubers were attached in chains that had two or more tubers. The percentages of tubers that were attached in chains of 2, 3, 4, 5, 6, 7, and 8 tubers constituted 24, 12, 6, 1, 2, 1 and 2% of the total population respectively. This followed an exponential pattern illustrated in Figure 4.1 that is characterized by the equation

$$\ln Y = \ln 111 - 0.43 X \quad (r^2 = .72).$$

(Y = total number of tubers in a given type of a chain per 0.1 m^2, X = number of tubers that determines the type of the chain).

The basal bulbs to which the leaves were attached weighed the least (Table 4.3). The greatest weight was in dormant tubers attached to a two-tuber parent chain. The weight was greatest in the parent tubers at the furthest point from leaves. New tubers, weighed more than basal bulbs but not weigh as much as the most basipetal tubers of parent tuber systems (.31 g vs .53 and .67 g) (Table 4.3).

Table 4.2. Frequency of parent and new tuber population in soil and their status.[x]

	Parent population										
	Sprouted										
	Tubers in a chain[y]									New population	
	1	2	3	4	5	6	7	8	Unsprouted[z]	Basal bulbs	New tubers
	(No/0.1 m^2)										
	76	37	24	14	2.0	3.6	2.9	4.9	69	147	72
$S_{\bar{y}}$	±9.5	±8.8	±7.3	±6.9	±1.2	±1.5	±1.7	±2.0	±14	±20	±6.7
Total	234									219	
	452										

[x] Average of five 30 cm by 30 cm by 30 cm deep samples.

[y] Chains are those with at least one tuber sprouted.

[z] Includes single tubers and tubers from chains where none had sprouted.

Generally more parent tubers were located in the deeper layers of soil and tubers in the deeper layers of soil have more percentage

Table 4.3. Fresh weight of different types of purple nutsedge tubers at 6 weeks.[x]

Type of tuber	Fresh weight[y] (g/tuber)
Basal bulb	.11d
New tuber	.31c
Single parent tuber	.53b
Sprouted tuber in a two-tuber chain	.31c
Unsprouted tuber in a two-tuber chain	.67a

[x] Average of five replicates.

[y] Means followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

of dry matter (Table 4.1). The fresh weight of parent tubers and those in deeper layers of soil were comparable to each other (Tables 4.1, 4.3). Considering that the majority of the field population in this study were parent tubers of high weight, it is concluded that more plant matter is found in the parent tubers than in the new tubers and basal bulbs of purple nutsedge at 6 weeks. This is important in controlling purple nutsedge using mechanical tillage. If deeper lying tubers are not affected by the tillage operations, they can establish healthy plants due to their stored food. Also, any chemical method of control must control the old tubers as well as the new.

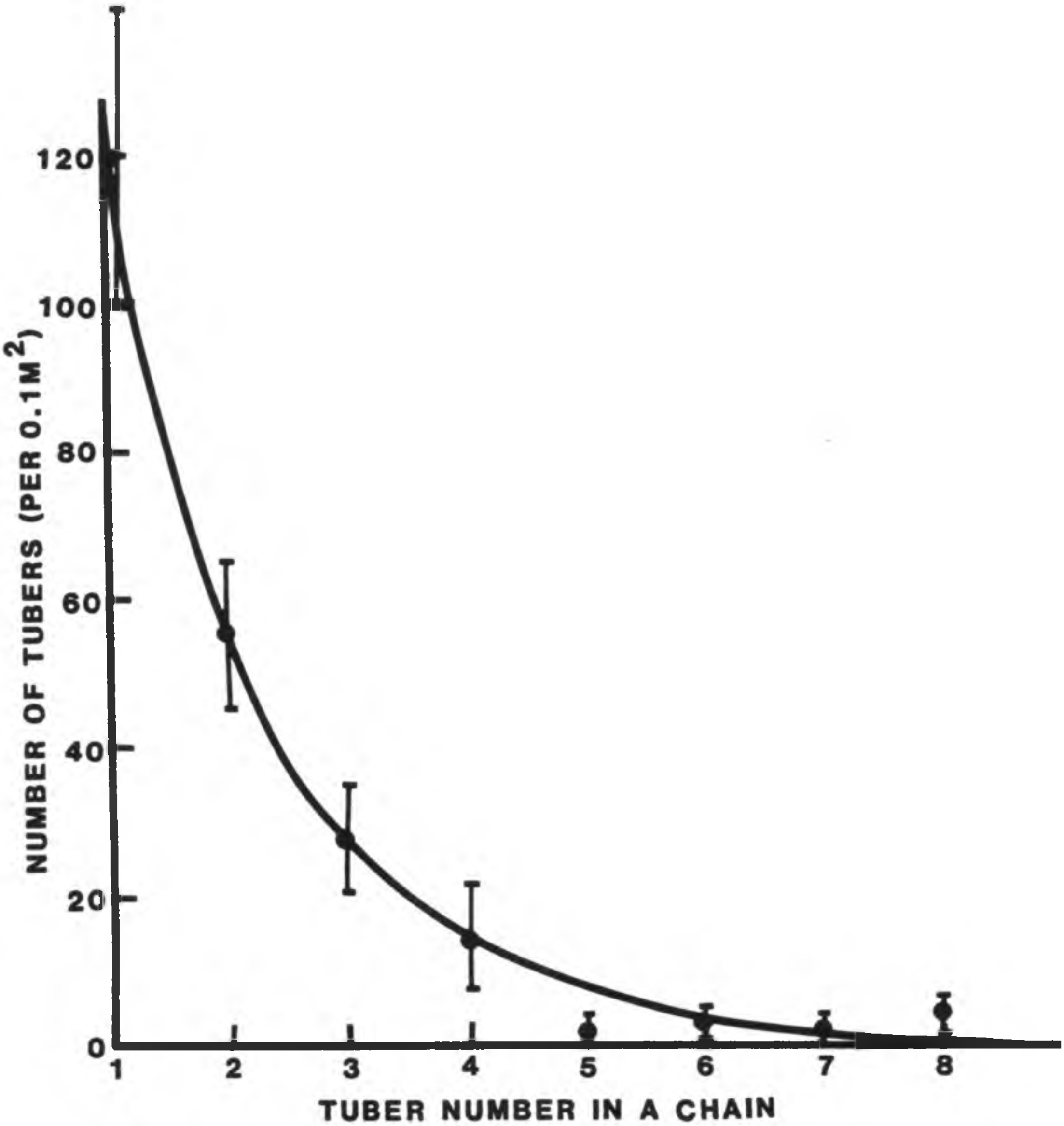

Figure 4.1. Occurrence of parent tubers of purple nutsedge singly and in chains in the field. The vertical bars represent plus or minus the standard error of the mean. (Average of five replicates).

Pattern of new tuber formation

New rhizomes developed from the basal bulb and the parent tuber following initial plant establishment (Table 4.4). The reduction of type A plants at 3 weeks from 63% to 40% at 6 weeks could be due to the formation of rhizomes from the parent tuber during this period, thus making type B from A. This is reflected in the increased percentage of type B at 6 weeks relative to 3 weeks. The increase in type C from 3 to 6 weeks could be to the sprouting of tubers unsprouted at 3 weeks, most of them resulting in type C. At 3 weeks, the top soil layer is likely to be saturated with rhizomes and basal bulbs. Therefore, any new growth is more likely to occur in the deeper layers of soil where less interference to growth is found. The suspected conversion of type A to B could be due to the same reason.

This hypothesis is further supported by the results of experiment 4 (Table 4.5). In this experiment, individual tubers were planted at three depths. The parent tubers produced rhizomes after the initial

Table 4.4. Occurrence of rhizomes developing from the basal bulb, parent tuber or both.[x]

Origin of new rhizome	Occurrence Week 3	Week 6
	------(%)-----	
A. New rhizomes only from the basal bulb	63+9	40+5
B. New rhizomes from both basal bulb and parent tuber	19+5	32+5
C. New rhizomes only from the parent tuber	18+6	28+4

[x] Average of five replicates.

Table 4.5. Occurrence of new rhizomes from the parent tuber at three planting depths 9 weeks after planting.[x]

Depth of planting	Parent tubers with new rhizomes[y]
(cm)	(%)
4	18c
8	27b
12	35a

[x] Average of six replicates.

[y] Means followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

plant establishment, however, at a low frequency of 35% at 12 cm. This low frequency in a nutsedge free area compared to 60% (32% + 28%) in an infested area (Table 4.4) could be partly due to the low plant density that was maintained in experiment 4.

When single tubers of purple nutsedge were planted in a purple nutsedge free area, the parent tubers produced new rhizomes after they formed first basal bulbs thus confirming the observations of experiment 3 (Table 4.5). The frequency of rhizome growth from parent tuber increased with planting depth. A regression analysis derived in the equation $Y = 1 + 0.83 X$ for linear regression (r^2=.72). (Y = number of parent tubers with new rhizomes forming from them, X = planting depth of tubers in cm).

Ranade and Burns (1925) reported that no new rhizomes are produced from the parent tuber once the plant produces its aerial connection. However, Horowitz (1972) reported that new rhizomes arose from both parent tuber and the basal bulb. Hence, the growth behavior of purple nutsedge differs with environment. This aspect of purple nutsedge growth has not been explored much. Further studies on the growth pattern of purple nutsedge in relation to the environment are therefore necessary.

Conclusion

Most tubers of purple nutsedge at Waimanalo were found in the top 16 cm of soil. Fifty one percent of the tubers at 6 weeks was from the parent population, whereas 49% was from the new generation of plants. Tubers from the parent population had more fresh weight than those from the new population. Parent tuber chains with up to eight tubers in a chain were found. Occurrence of parent tubers as single or in a chain followed a logarithmic decay pattern. Fifteen percent of all the tubers at 6 weeks were unsprouted parent tubers. This averaged to 750 tubers/m^2.

The understanding of climatic conditions afffecting the growth of purple nutsedge is far from complete. The conflicting evidence on its growth pattern and the wide range in tuber populations in soil can be due to the differences in the environment. Therefore, for a better management of purple nutsedge, on-site studies pertinent to its growth are necessary.

CHAPTER V

EFFECT OF LOW RATES OF GLYPHOSATE ON PURPLE NUTSEDGE GROWTH AND TUBER SPROUTING

Abstract. Low rates of glyphosate (*N*-(phosphonomethyl)glycine) are known to reduce field populations of purple nutsedge (*Cyperus rotundus* L.). Glyphosate was applied at 0.0, 0.25, 0.5, 1.0 and 2.0 kg ae/ha to purple nutsedge plants grown 6 weeks in pots. Tubers of treated plants were separated 3 weeks after spraying and incubated in petri dishes for 10 weeks. The experiment was repeated 10 times at 6 week intervals. At 0.25 kg/ha glyphosate, tuber number often increased, but the herbicide did not alter the fresh weight of tubers and leaves or tuber sprouting. Tuber number was reduced by 1.0 and 2.0 kg/ha glyphosate. Tuber fresh weight was reduced by every application of 2.0 kg/ha glyphosate, between November and June by 1.0 kg/ha and between November and January by 0.5 kg/ha. Rates of 0.5 kg/ha and higher reduced fresh weight of leaves. Percent sprouting of tubers from plants treated with 0.5, 1.0 and 2.0 kg/ha glyphosate was higher during August, September and April than during other months of the year. The changes in tuber sprouting with 1.0 kg/ha glyphosate was related to the ratio of fresh weight of tubers to fresh weight of leaves at time of glyphosate application. Therefore, glyphosate at 0.5 kg/ha could be used to reduce field populations of purple nutsedge.

Introduction

Purple nutsedge is a major weed in tropical crops (Holm *et al.*, 1977). It is propagated by underground tubers and basal bulbs.

Glyphosate is effective in controlling purple nutsedge at 2.0 to 4.0 kg ae/ha (Baird *et al.*, 1971; Magambo and Terry, 1973; Toth and Smith, 1979). However, these rates of glyphosate are expensive for the user and do not eradicate this weed (Magambo and Terry, 1973; Zandstra *et al.*, 1974). Low levels of glyphosate however, have reduced field populations of purple nutsedge (Doll and Piedrahita, 1982; Toth and Smith, 1979). Doll and Piedrahita (1982) and Toth and Smith (1979) observed a seasonal variation of glyphosate activity on purple nutsedge tuber sprouting.

This study was conducted to determine the effect of low levels of glyphosate on purple nutsedge applied during different times of the year.

Materials and Methods

The experiment was conducted at the Magoon facility of the University of Hawaii, Manoa. Black plastic pots with a diameter of 15 cm and a volume of 2,800 cm^3 were filled with vermiculite/perlite/peat moss at 1:1:1 (v/v/v) ratio. Two freshly harvested purple nutsedge tubers were planted in each pot and 14:14:14 osmocote (3 month release rate) at 2,000 kg/ha rate was applied to each pot. Pots were kept outdoors and irrigated twice daily. Plants were thinned to one plant per pot after a week.

After 6 weeks, five plants were removed from the pots and the fresh weight of leaves and tubers and basal bulbs was recorded. The remaining plants were treated with glyphosate at 0.0, 0.25, 0.5, 1.0 and 2.0 kg ae/ha with five replications per rate. All rates of glyphosate were applied in 375 l/ha water solution. Pots were kept indoors for 24 h, then placed on an outdoor bench.

After 3 weeks, the plants were harvested and the fresh weight of leaves and tubers was recorded. The tubers were separated and incubated in petri dishes at 23 C. After 3 weeks, 10 ml of 100 ppm w/w benzyl adenine in water was added to each petri dish. Counts of tuber sprouting were taken at weekly intervals for 10 weeks.

This process was repeated 10 times at 6 week intervals.

Analysis of results was conducted as a completely randomized design for each time of application. For tuber sprouting, the cumulative sprouting over 10 weeks was used for analysis using the percent sprouting.

Results and Discussion

At the time of herbicide application, fresh weight of leaves and tuber numbers was highest during the summer months and lowest during the winter months (Table 5.1). The greatest tuber fresh weight to leaf fresh weight ratios were in January and March. Similar increases in tuber weight to leaf weight ratios in purple nutsedge under short days were observed by Berger and Day (1967) and Hammerton (1975). In Hawaii, the shortest day of 10.8 h occurs in December and longest day of 13.2 h occurs in June.

Table 5.1. Status of purple nutsedge at time of glyphosate application at different times of the year.[x,y]

Treatment date	Fresh weight Leaf	Fresh weight Tuber	Tuber fresh weight/Leaf fresh weight	Tuber number	Weight/ tuber
	----(g)----			(No)	(g)
08-11-82	35ab	12a	.34bc	29bcd	.41ab
09-22-82	29bc	14a	.47b	33ab	.42ab
11-03-82	43a	13a	.30c	31a-d	.42ab
12-15-82	28bc	4c	.14d	24cde	.17c
01-27-83	8d	6bc	.75a	17ef	.35b
03-17-83	15d	11a	.69a	22c-f	.50a
04-28-83	14d	5c	.37bc	14f	.36b
06-09-83	18cd	10ab	.37bc	23cde	.22c
07-22-83	41a	14a	.27cd	39a	.36b
08-30-83	39ab	13a	.34bc	32abc	.41ab

[x] Average of five replicates.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

Glyphosate at 0.25 kg/ha increased tuber number per plant, between April and August (Table 5.2). During other periods there was no effect in tuber number with 0.25 kg/ha glyphosate. At 0.5 kg/ha, no changes in tuber number occurred as compared with the untreated control.

Increased tuber production occurred in the first basal bulbs indicating a release of apical dominance at 0.25 kg/ha glyphosate (Figure 5.1). Low levels of glyphosate released apical dominance and increased bud development in quackgrass (*Agropyron repens* L.), sorghum (*Sorghum bicolor* L.) and wheat (*Triticum aestivum* L.) (Baur *et al*., 1977; Coupland and Caseley, 1975). Increased tuber production in yellow nutsedge occurred with 0.5 kg/ha of glyphosate (Linscott and Hagin, 1973).

Glyphosate at 1.0 kg/ha reduced the tuber number compared to the untreated control only in November, December and June applications (Table 5.2). However, at 2.0 kg/ha, glyphosate reduced the number of tubers at every application.

An increase in tuber fresh weight occurred in April, July and early August with application of 0.25 kg/ha glyphosate (Table 5.3). Generally this coincided with an increase in tuber number (Table 5.2). At 0.5 kg/ha, fresh weight reductions of tubers occurred between November and January. With 1.0 kg/ha, fresh weight of tubers was reduced between November and June except for the April application. Glyphosate at 2.0 kg/ha reduced the fresh weight of purple nutsedge tubers in all but the April and July application.

Glyphosate at 0.25 kg/ha reduced the fresh weight of leaves at some application dates but not at others (Table 5.4). At 0.5 kg/ha,

Table 5.2. Number of purple nutsedge tubers 3 weeks after application of glyphosate at four rates at different times of the year.[xy]

Rate of glyphosate (kg/ha)	Date of application of glyphosate									
	1982				1983					
	08-02	09-22	11-03	12-15	01-27	03-17	04-28	06-09	07-22	08-30
	(tubers/plant)									
0.0	72b	71a	83a	53a	46a	48b	53bc	71b	71b	85a
0.25	102a	65ab	102a	60a	45a	59ab	82a	91a	105a	89a
0.5	72b	66ab	60a	56a	44a	63a	61b	82ab	89ab	75a
1.0	54bc	60ab	26b	29b	42a	45b	39cd	36c	72b	77a
2.0	34c	48b	26b	20b	13b	27c	31d	28c	45c	35b

[x] Average of five replicates.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

Figure 5.1. Multiple sprouts in purple nutsedge after application of glyphosate at 0.25 kg/ha.

Table 5.3. Fresh weight of tubers of purple nutsedge 3 weeks after application of glyphosate at four rates at different times of the year.[xy]

Rate of glyphosate (kg/ha)	Date of application of glyphosate: 1982 08-02	1982 09-22	1982 11-03	1982 12-15	1983 01-27	1983 03-17	1983 04-28	1983 06-09	1983 07-22	1983 08-30
	(g/plant)									
0.0	60a	42ab	43a	22a	19a	22a	17b	32a	31b	29ab
0.25	60a	43a	45a	19a	16ab	24a	23a	35a	49a	37a
0.5	46b	40ab	22b	13b	13b	20ab	18ab	32a	33b	28b
1.0	39b	36ab	11c	8b	11b	16bc	16b	15b	27b	26b
2.0	27c	31b	10c	8b	4c	12c	11b	11b	23b	15c

[x] Average of five replicates.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

Table 5.4. Fresh weight of purple nutsedge leaves 3 weeks after application of glyphosate at four rates at different times of the year.[xy]

Rate of glyphosate (kg/ha)	Date of application of glyphosate									
	1982				1983					
	08-02	09-22	11-03	12-15	01-27	03-17	04-28	06-09	07-22	08-30
	(g/plant)									
0.0	38a	39a	58a	29a	33a	29a	32ab	50a	51a	63a
0.25	29b	35a	42b	25a	25b	24ab	39a	37b	48a	48b
0.5	24bc	37a	26c	13b	17c	17bc	30b	39b	37ab	41b
1.0	19c	36a	8d	9b	16c	12cd	16c	24c	34b	44b
2.0	12d	23b	9d	7b	5d	6d	14c	20c	26b	28c

[x] Average of five replicates.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

glyphosate reduced the leaf fresh weight except in April, July and September. At 1.0 kg/ha, reductions of fresh weight of leaves occurred at all dates except in September. Fresh weight of leaves was reduced at all applications of 2.0 kg/ha.

These fresh weight reductions by glyphosate agree with observations on quackgrass, wheat and sorghum (Baur et al., 1977; Coupland and Caseley, 1975).

Percent sprouting of tubers as a result of glyphosate treatment changed with rate and the time of year (Table 5.5). Glyphosate at 0.25 kg/ha did not reduce sprouting except in December. In September, glyphosate at 0.25 increased the percent tuber sprouting. At 0.5 kg/ha glyphosate reduced the percent sprouting of tubers except in September, April and August. Glyphosate at 1.0 kg/ha reduced the percent tuber sprouting at every application except in September. At 2.0 kg/ha tuber sprouting was reduced from all applications.

The percent sprouting of tubers with 1.0 and 2.0 kg/ha glyphosate was not uniform throughout the experiment (Table 5.5). At 2.0 kg/ha glyphosate, no tubers sprouted in 6 of 10 application times, but 56% of the tubers sprouted in the September application. In July and late August, 22 and 12% of the tubers sprouted after treatment with 2.0 kg/ha of glyphosate. At 1.0 kg/ha glyphosate, sprouting ranged from 0 in December to 85% in September.

There was no reasonable explanation for the differences in glyphosate activity on tuber sprouting during different times of the

Table 5.5. Percent tuber sprouting of purple nutsedge after application of glyphosate at four rates at different times of the year.[x][y]

Rate of glyphosate (kg/ha)	Date of application of glyphosate									
	1982				1983					
	08-02	09-22	11-03	12-15	01-27	03-17	04-28	06-09	07-22	08-30
	(% sprouting)									
0.0	85a	80b	82a	77a	84a	81a	68a	70a	80a	75ab
0.25	76ab	95a	79a	63b	72ab	85a	59a	74a	80a	82a
0.5	62b	89ab	58b	21c	57bc	65b	25b	52b	63b	69b
1.0	39c	85b	15c	0d	41c	32c	8c	6c	47c	55c
2.0	0d	56c	0c	0d	0d	0d	7c	0c	22d	12d

[x] Average of five replicates.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

year. However, the growth of the plants at the time of application of glyphosate was different at different times of the year (Table 5.1).

Due to the differences in tuber fresh weight to leaf fresh weight ratios, tubers at different times of the year could get different amounts of glyphosate. This ratio, at the time of glyphosate application followed the same pattern as the percent sprouting of tubers from the glyphosate at 1.0 kg/ha rate (Figure 5.2). Rates of 0.25 and 0.5 kg/ha were not high enough to be toxic and 2.0 kg/ha was too toxic to draw similar comparisions.

Between June and September, the tuber weight to leaf weight ratio did not compare as well with percent sprouting of tubers with 1.0 kg/ha glyphosate as during other periods (Figure 5.2). It is possible that the high leaf number that is associated with high leaf weight during these times prevented complete coverage of glyphosate due to overlapping of the leaves thus causing a reduced effect by glyphosate. Doll and Piedrahita (1982) found that partial coverage of purple nutsedge during glyphosate treatment reduced inhibition of tuber sprouting. Therefore, the differences in tuber sprouting may be associated with the coverage of the plant with glyphosate and the tuber weight to leaf weight ratio.

The results of these experiments do not agree with those of field experiments (Chapter III). In general glyphosate gave a greater suppression of tuber sprouting in the pot study than in the field trials. No sprouting of basal bulbs or tubers occurred in the

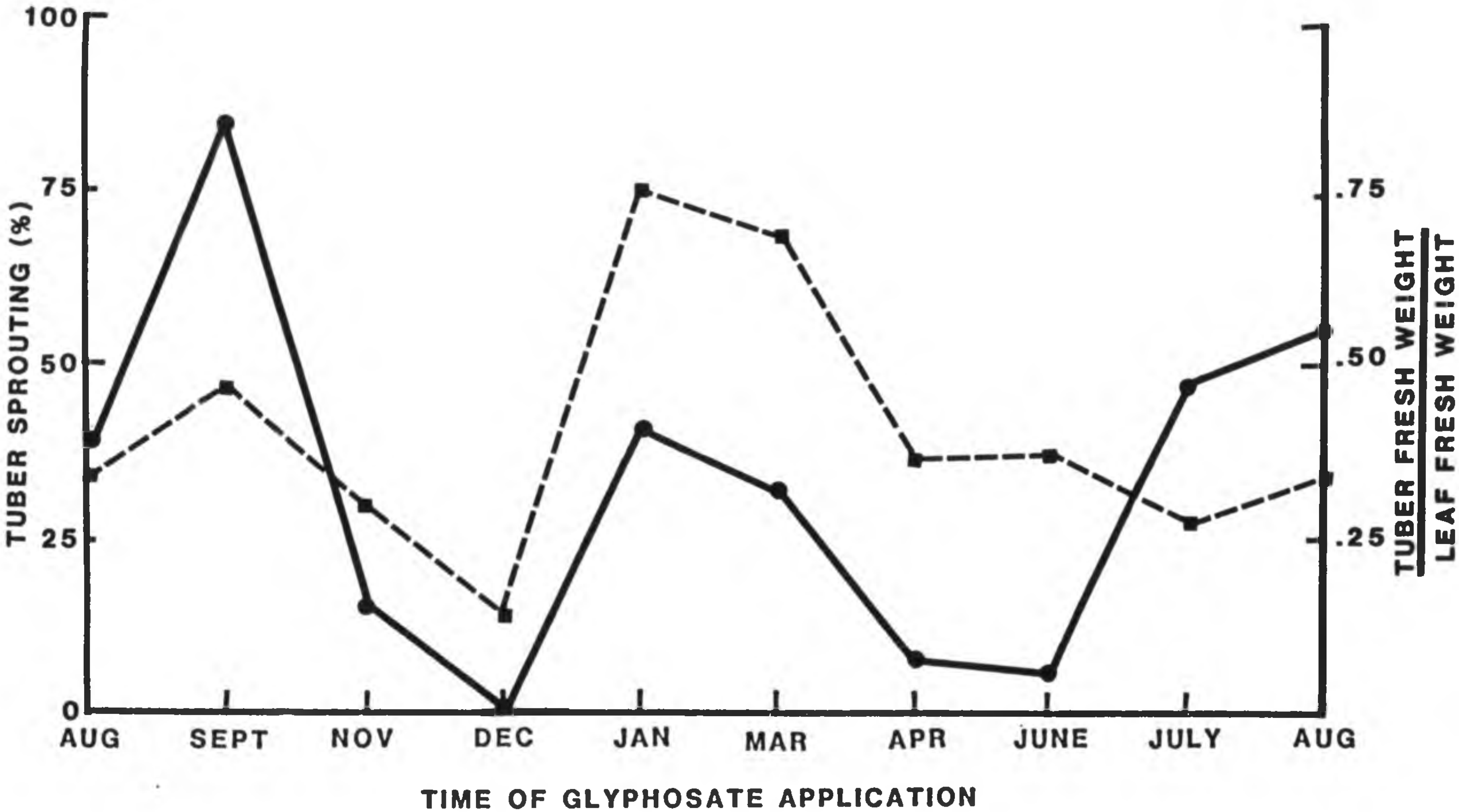

Figure 5.2. Relationship between the ratio of fresh weight of tubers to fresh weight of leaves of purple nutsedge (———) and tuber sprouting with 1.0 kg/ha glyphosate (━━━━). (Average of five replicates).

March treatment with 2.0 kg/ha glyphosate in pot experiments whereas the basal bulbs were unaffected in the field in March.

The differences in glyphosate activity in pot and field experiments could be due to the differences in tuber fresh weight to leaf fresh weight ratios. The activity of glyphosate at 1.0 kg/ha is related to the ratio of fresh weight of tubers to fresh weight of leaves. Plants in the pot experiments probably had a higher leaf weight to tuber weight ratio than those in the field. The plants in pots had no dormant tubers, and all the tubers except the newly developing ones and the planted tuber had above ground parts, whereas in the field, only 32% of tubers had above ground parts (Chapter IV). Hence, it is likely that less glyphosate entered the tubers in the field than in the pots at a given rate of glyphosate application, resulting in less activity in the field.

Purple nutsedge grows best at 32 C (William and Warren, 1975a; Wills, 1975). The lower temperatures in March (Chapter III) could also account for lesser foliar growth vis-a-vis June and October. This would reduce the foliar surface available to intercept the herbicide spray. Therefore, the reduced effect of glyphosate applied in March could have been a combination of less foliar exposure to glyphosate and a slower rate of translocation resulting from the slower assimilate production due to lower temperature.

Conclusion

Glyphosate at 0.5 kg/ha reduced the sprouting of purple nutsedge tubers except for the September and April applications. At 1.0 and 2.0 kg/ha, glyphosate reduced sprouting except for the September at

1.0 kg/ha treatment. Glyphosate at 0.25 kg/ha, did not decrease the the number or the fresh weight of tubers and leaves at any time, however it did increase the tuber number at times. At 0.5 kg/ha, glyphosate did not change the number of tubers formed, but decreased the percent sprouting. Rates of 1.0 and 2.0 kg/ha reduced both tuber formation and sprouting. Therefore, it would appear that glyphosate at 0.5 kg/ha or above may be used to decrease field populations of purple nutsedge.

CHAPTER VI

EFFECT OF POST-HARVEST APPLICATION OF LOW LEVELS OF GLYPHOSATE FOR PURPLE NUTSEDGE ON TRANSPLANTED LETTUCE AND DIRECT SEEDED GREEN BEAN

Abstract. Glyphosate (*N*-(phosphonomethyl)glycine) at 0.5 and 1.0 kg ae/ha was applied to purple nutsedge (*Cyperus rotundus* L.), post-harvest in a 13 month, six crop cycle experiment of continuous green bean, (*Phaseolus vulgaris* L.) continuous lettuce (*Lactuca sativa* L.) and a rotation of the two crops. The effect of glyphosate under no-till conditions was also tested. Glyphosate reduced the emergence and height of purple nutsedge during the crop cycles following application. At the end of 13 months, glyphosate treated plots and hand weeded plots had fewer tubers than the untreated plots. Tuber weight of purple nutsedge in no-till plots was higher than in rotovated plots. Purple nutsedge height increased with increasing air temperature. Crop height increased with purple nutsedge height but was not correlated with air temperature. Purple nutsedge did not affect fresh weight of bean pods or the dry weight of bean leaves and stems at any crop cycle. Lettuce fresh weight, dry weight and mean daily dry matter accumulation was reduced by purple nutsedge during the summer. The percent reduction of fresh weight, dry weight and mean daily dry matter accumulation of lettuce in unweeded plots increased as purple nutsedge height and volume (purple nutsedge height (cm) x purple nutsedge plant number) increased but did not relate to the purple nutsedge plant number. Mean separation by single degree of freedom showed that 1.0 kg/ha

glyphosate helped to increase lettuce fresh weight over not weeding from the second crop cycle in all months except during September.

Introduction

Purple nutsedge (*Cyperus rotundus* L.) is a major weed in tropical crops (Holm *et al*.,1977). Yield losses to purple nutsedge differ in different crops. Crops that form a canopy in a short time are less affected by purple nutsedge (William and Warren, 1975a).

Transplanted cabbage (*Brassica oleracea* L.), green bean (*Phaseolus vulgaris* L.), and cucumber (*Cucumis sativus* L.) competed better with purple nutsedge than garlic (*Allium sativum* L.) and okra (*Hibiscus esculentus* L.) (William and Warren, 1975a). Yield of a tall variety of carrot (*Daucus carota* L.) 'Kuroda' was less affected than a short variety 'Nantes'. In upland rice (*Oryza sativa* L.), increased purple nutsedge density decreased the grain yield (Okafor and De Datta, 1976).

Glyphosate (N-(phosphonomethyl)glycine) at 2.0 to 4.0 kg ae/ha is effective against purple nutsedge (Baird *et al*., 1971). The use of glyphosate at these rates is expensive and did not eradicate purple nutsedge even with repeated applications (Klosterboer, 1974; Koogan and Gonzales, 1979; Zandstra *et al*., 1974; Zandstra and Nishimoto, 1975).

Low rates of glyphosate, applied once or repeatedly, reduced populations of purple nutsedge during the following seasons (Doll and Piedrahita, 1982; Toth and Smith, 1979; Zandstra *et al*., 1974).

Therefore, low rates of glyphosate may reduce the population of purple nutsedge sufficiently to avoid crop yield losses.

The objective of this study was to determine the effect of post harvest applications of glyphosate at 0.5 and 1.0 kg/ha to manage purple nutsedge in a six crop cycle experiment. These glyphosate rates are substantially lower than normally recommended for purple nutsedge control. The crops were green beans planted continuously, lettuce (Lactuca sativa L.) planted continuously, and a lettuce/bean rotation. Effect of glyphosate at 1.0 kg/ha was also determined under no-till conditions.

Materials and Methods

The experiment was conducted at the Waimanalo Research Station, Oahu, Hawaii. The soil was a typic haplustol with a pH of 5.3.

A field infested with purple nutsedge was rotovated and leveled. Permanent plots were kept for six crop cycles. Plots to be planted with lettuce continuously were 1.2 m by 7.2 m. Those to be planted with lettuce/bean rotation and bean continuously were 1.8 m by 7.2 m. Four replicates were used. A space of 0.6 m separated plots within a replicate with 1.2 m between replicates. Plots receiving no-till treatments were on one side of the block in a split plot design.

Lettuce 'Manoa' (From Fukuda Seed Company, Honolulu) seeds were planted in styrofoam trays in 7.5 cm by 7.5 cm compartments in a mixture of vermiculite, perlite and peat moss in a 2:2:1 (v/v/v) ratio. Two seeds per compartment were planted. Osmocote 14:14:14 (3 month release rate) was applied at 1,000 kg/ha and the trays were kept in a glass house and irrigated twice daily. Seven days later, the seedlings were thinned to one per compartment. Seedlings were transplanted in the field at 3 to 4 weeks.

Lettuce was transplanted at 20 cm intervals within a row in rows 30 cm apart. Plots planted with lettuce continuously had four rows, and those planted with lettuce/bean rotation had six rows of lettuce.

Bean 'Green Crop' seeds (From Fukuda Seed Company, Honolulu), were planted in 4 rows 45 cm apart. Within a row, two seeds were planted every 10 cm. After germination, the seedlings were thinned to one plant.

Control of weeds other than purple nutsedge in bean was made by spraying trifluralin (α,α,α-trifluoro-2,6-dinitro-*N*,*N*-diphenyl -*p*-toluidine) at 1.0 kg ai/ha after seeding followed by irrigation. For lettuce, pronamide (3,5-dichloro(*N*-1,1-dimethyl-2-propynyl) benzamide) was sprayed at 2.0 kg ai/ha after planting, followed by irrigation. Hand weeding 2 to 3 weeks later supplemented weed control by herbicides.

In a replicate, three plots that were planted with lettuce and bean continuously and in rotation were weeded free of purple nutsedge. Weeding was made at 2 and 4 weeks after planting. Three similar plots were kept without control of purple nutsedge. Glyphosate as a post harvest treatment was used for the rest. The treatments are detailed in Table 6.1.

Table 6.1. The treatments of the experiment on post-harvest application of glyphosate at Waimanalo.

	Rotovated			No-till		
	Crop			Crop		
Treatment	Lettuce	Rotation	Bean	Lettuce	Rotation	Bean
Hand-weeded	+	+	+			
Unweeded	+	+	+			
Glyphosate 0.5 kg/ha	+	+	+			
Glyphosate 1.0 kg/ha	+	+	+	+	+	+

Fertilizer (10:30:10 $N:P_2O_5:K_2O$) was applied at 1,000 kg/ha rate for lettuce (100:130:80 kg N:P:K/ha) in split applications before planting and 3 to 4 weeks later. Bean plots received the same fertilizer at 2,000 kg/ha (200:260:160 kg N:P:K/ha) in split applications before seeding and 4 weeks later. Plots were overhead irrigated three times weekly with 1.5 to 2.0 cm water at each irrigation. Levels of fertilizer and water applied were presumed to be at non-limiting levels.

Glyphosate was applied soon after harvest of each crop after removing crop residues from the plots. The rates used were 0.5 and 1.0 kg/ha for rotovated plots and 1.0 kg/ha for no-till plots. The volume rate utilized was 375 l/ha.

Seven days after glyphosate application, the field was rotovated except for the no-till area. The field was leveled and the next crop was planted. The timing of the operations are detailed in Table 6.2.

Table 6.2. Dates of operations of the experiment at Waimanalo.

Crop cycle	Planting		Harvest		Glyphosate application	
	Lettuce	Bean	Lettuce	Bean	Lettuce	Bean
	(date)					
1	02-10-84	02-06-84	03-16-84	03-29-84	03-19-84	04-13-84
2	05-02-84	04-19-84	05-30-84	06-13-84	06-06-84	06-19-84
3	06-28-84	06-28-84	07-24-84	08-16-84	07-25-84	08-16-84
4	09-10-84	08-31-84	10-03-84	10-25-84	10-05-84	10-28-84
5	11-19-84	11-14-84	12-19-84	01-08-84	12-22-84	01-12-84
6	01-28-85	01-28-85	03-12-85	03-25-85	04-01-85	04-01-85

This process was repeated until six crop cycles were completed. The plots under rotation were planted with lettuce during the first, third and fifth seasons.

During each crop cycle, the following data were taken:

1) Crop and purple nutsedge plant height 4 weeks after crop establishment. The height of 10 plants was recorded from each plot.

2) Purple nutsedge plant counts in two randomly selected 30 cm by 30 cm quadrats in each plot 4 weeks after crop establishment.

3) Weekly expansion of leaves into row interface. For lettuce, diameter of the crown from above was taken from ten plants. For bean, ten observations of the spread of leaves across a row was taken at 10 cm distances from above.

4) Fresh weight of the above ground parts of lettuce and bean pods from each plot leaving one border row at maturity.

5) Fresh and dry weight of above ground parts of five lettuce plants from each plot at time harvesting. Dry weight was obtained after drying the plants at 65 C for 2 weeks.

6) Fresh and dry weight of bean plants from 1 m of a center row in each plot at time of harvesting. Dry weight was obtained by drying the plants at 65 C for 1 week.

7) Number of bean plants harvested.

8) Number of lettuce plants harvested.

9) Daily minimum and maximum temperatures.

At the end of the sixth crop cycle, one half of every plot that received glyphosate was again sprayed with glyphosate at the same rate. The field was rotovated 7 days later except the no-till area, leveled, and irrigated. The no-till area was surface hoed clean of weeds before irrigation. Purple nutsedge counts were taken 3 weeks later from two 30 cm by 30 cm quadrats from each half.

Soon after the sixth crop cycle, two blocks of soil measuring 30 cm by 30 cm and 20 cm deep were dug from each plot. The soil was washed and the tubers were separated. The tubers were counted, dried at 65 C for 7 days and weighed.

Analysis of variance on purple nutsedge data was conducted for each crop cycle separately. The rotovated plots were analyzed as a randomized complete block. Separate analysis was conducted for rotovated and no-till plots at 1.0 kg/ha glyphosate as a split plot with land preparation as the main plot treatment.

For the crops, analysis of variance for individual crop cycles was conducted as a split plot design with land preparation as the main plot treatment. A separate series of analysis on seasonal differences in crops in weeded and unweeded plots was conducted in a split plot design with the crop cycle as the main plot treatment.

Results and Discussion

Purple nutsedge growth and its responses to glyphosate

Purple nutsedge emergence

Except during the fourth crop cycle, the crop species did not affect purple nutsedge emergence in untreated plots (Table 6.3). More purple nutsedge emerged during the fourth and fifth crop cycles than at other times which coincided with the September and November emergence period. Optimum temperature for purple nutsedge tuber sprouting is 35 C (Ueki, 1969). Tubers do not sprout below 15 C (Cools and Locascio, 1977; Ueki, 1969). The air temperature at Waimanalo rose from 25 C in January to 32 C in September (Table 6.4). Therefore, the maximum emergence of purple nutsedge can be expected during September when optimum temperatures are approached.

Glyphosate reduced the emergence of purple nutsedge during the following crop cycle (Table 6.3). Glyphosate at 0.5 was as effective as 1.0 kg/ha in reducing purple nutsedge emergence. However, during the fourth crop cycle under crop rotation when the untreated control plots had the highest population of purple nutsedge, 0.5 kg/ha of glyphosate was not as effective in reducing the purple nutsedge population as 1.0 kg/ha.

Table 6.3. Purple nutsedge counts at 3 weeks after crop establishment during six crop cycles.[x]

	Number of purple nutsedge plants[y]					
	Crop cycle					
Crop	1	2	3	4	5	6
	(plants/0.1 m^2)					
unweeded						
Lettuce	55a	52a	63a	44cd	84a	48a
Lettuce/bean[z]	39a	43ab	50a	110a	84a	52a
Bean	68a	39abc	48a	81b	81a	52a
glyphosate 0.5 kg/ha[u]						
Lettuce	38a	22cd	15b	16e	22b	8b
Lettuce/bean	55a	22cd	19b	71bc	25b	14b
Bean	67a	22cd	20b	12e	23b	8b
glyphosate 1.0 kg/ha						
Lettuce	92a	18d	11b	18de	12b	7b
Lettuce/bean	74a	16d	11b	24de	14b	6b
Bean	60a	22cd	10b	20de	17b	9b

[x] Average of eight 0.1 m^2 quadrats.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

[u] Lettuce was planted during crop cycles 1, 3 and 5. Bean was planted during crop cycles 2, 4 and 6.

[v] Glyphosate was applied soon after harvest of previous crop. No glyphosate was applied prior to first planting.

Table 6.4. Mean air temperature and height of purple nutsedge in crops and of lettuce and bean in weeded and unweeded plots 4 weeks after planting.[x]

		Mean air temperature		Plant height[y]						
				Purple nutsedge in			Lettuce		Bean	
Crop cycle	Months	Minimum	Maximum	Lettuce	Rotated[z]	Bean	Weeded	Unweeded	Weeded	Unweeded
		--(C)--		--------------------(cm)--------------------						
1	February/March	20	25	13e	13e	20b	13bc	13bc	40abc	44ab
2	April/June	22	28	12e	18bcd	19bc	6d	6d	33cd	34cd
3	June/August	23	30	19bc	18bcd	20b	12c	14bc	33cd	30d
4	September/October	23	31	20b	29a	33a	14bc	17a	35bcd	48a
5	November/January	21	27	15cd	16b-e	18bcd	15ab	14bc	31d	33cd
6	February/March	18	26	14de	13e	13e	14bc	14bc	29d	33cd

[x] Average of four replicates and 10 plants from each replicate.

[y] Means followed by the same letter under each species are not significantly different at P=0.05 by Duncan's multiple range test.

[z] Lettuce was planted during crop cycle 1.

At 1.0 kg/ha of glyphosate, more purple nutsedge emerged in rotovated plots than in no-till plots during the third and fifth crop cycles (Table 6.5). During the fourth crop cycle, there was an increase in emergence, probably due to the high temperature. However, the low stand of purple nutsedge during the previous season (Table 6.3) may have exposed less leaves to glyphosate, hence less glyphosate was translocated to the tubers thus increasing the number of sprouted tubers during the fourth crop cycle. The decreased emergence of purple nutsedge during the fifth crop cycle, particularly in the no-till plots, also could be due to a similar effect where more plants were exposed to glyphosate during the fourth crop cycle. During the sixth crop cycle, a lack of differences in purple nutsedge emergence between the rotovated and the no-till plots may have been due to lower temperature.

After one half of the plots was treated with glyphosate at the end of the experiment, purple nutsedge emergence in rotovated plots was not different between the treated and untreated halves (Table 6.6). Hand weeded plots had similar purple nutsedge emergence as in glyphosate treated plots.

The absence of differences in the rotovated plots could be due to the low temperature during this time of the year. Also, there were fewer purple nutsedge plants in the treated plots during the previous season (Table 6.3). As a result, less glyphosate may have entered the underground tubers than during the previous seasons.

Table 6.5. Purple nutsedge counts 3 weeks after crop establishment in rotovated and no-till plots with 1.0 kg/ha glyphosate.[xyz]

Land preparation	Crop	Number of purple nutsedge plants — Crop cycle 1	2	3	4	5	6
		(plants/0.1 m^2)					
Rotovated	Lettuce	92a	18a	11a	18b	12ab	7a
	Lettuce/bean[u]	74a	16a	11a	24b	14a	6a
	Bean	60a	22a	10ab	20b	17a	9a
No-till	Lettuce	53a	17a	4c	10b	1c	5a
	Lettuce/bean	56a	22a	7bc	46a	2bc	12a
	Bean	79a	21a	6c	25ab	5bc	11a

[x] Average of eight 0.1 m^2 quadrats.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

[z] Glyphosate was applied soon after harvest of previous crop. No glyphosate was applied prior to first crop.

[u] Lettuce was planted during the crop cycles 1, 3 and 5. Bean was planted during crop cycles 2, 4 and 6.

Table 6.6. Purple nutsedge emergence at 3 weeks from two halves of plots after one half was treated with glyphosate after six crop cycles.[xy]

	Number of plants	
Crop	Unsprayed	Sprayed
	---(plants/0.1 m^2)---	
-----------clean weeded------------		
Lettuce	17bcd	
Lettuce/bean	8d	
Bean	10d	
------------unweeded---------------		
Lettuce	48a	
Lettuce/bean	36abc	
Bean	42ab	
--------glyphosate 0.5 kg/ha--------		
Lettuce	8d	4d
Lettuce/bean	7d	5d
Bean	11cd	6d
--------glyphosate 1.0 kg/ha--------		
Lettuce	8d	3d
Lettuce/bean	6d	4d
Bean	6d	7d

[x] Average of eight 0.1 m^2 quadrats.

[y] Means followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

However, more purple nutsedge emerged from the unsprayed half of no-till plots than from the sprayed half (Table 6.7). This suggests that glyphosate had not killed the tubers but prevented them from sprouting. The increased plant number in the unsprayed half could be due to several reasons.

The plants from the sixth crop cycle in the unsprayed half could continue to grow in spite of being surface hoed. However, glyphosate may have killed or supressed the growth of the previously emerged shoots in the sprayed half.

The unsprayed half was characterized by purple nutsedge plants without apical dominance (Figure 6.1). Some plants in the unsprayed half were short and occurred in clusters. It is possible that glyphosate from the previous application continued to affect the purple nutsedge even though the tubers sprouted. In the sprayed half the cumulative effect of glyphosate from the previous application and the current, may have been sufficient to inhibit the tuber sprouting. This would suggest the requirement for a continuous post-harvest glyphosate application under no-till conditions.

The unsprayed half of the no-till plots in general contained more purple nutsedge plants than in the unweeded controls (Tables 6.5,6.6). This could be partly due to the clustered plants in the glyphosate treated plots and also to an increased percent sprouting of tubers in no-till plots due to low levels of glyphosate. An occasional increased percent tuber sprouting was observed previously with 0.25 kg/ha glyphosate (Chapter V).

Table 6.7. Purple nutsedge emergence at 3 weeks from the two halves of rotovated and no-till plots that received 1.0 kg/ha glyphosate during the experiment, when only one half was sprayed with glyphosate.[x,y]

Land preparation	Crop	Number of plants: Unsprayed	Number of plants: Sprayed
		---(plants/0.1 m^2)--	
Rotovated	Lettuce	8b	3b
	Lettuce/bean	6b	4b
	Bean	6b	7b
No-till	Lettuce	78a	16b
	Lettuce/bean	91a	15b
	Bean	61a	15b

[x] Average of eight 0.1 m^2 quadrats.

[y] Means followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

Figure 6.1. Multiple sprouts of purple nutsedge after application of glyphosate at 1.0 kg/ha under no-till.

Effect of glyphosate on tuber number and weight

At the end of six crop cycles, unweeded plots contained the largest number of purple nutsedge tubers (290 to 350/0.1 m^2) (Table 6.8). Rotovated plots that were hand weeded or treated with 0.5 and 1.0 kg/ha of glyphosate had equal number of tubers. Handweeding depletes the food reserves of the tubers. Therefore, a reduction in tuber number was possible after handweeding in six continuous crop cycles. The reduction in tuber numbers by glyphosate could be partially due to the death of tubers by glyphosate and partly due to the weak plants that may be produced as a result of residual glyphosate (Figure 6.2). The loss of apical dominance within the tuber chain as a result of rotovation could also result in increased tuber sprouting and thus more glyphosate reaching tubers.

At the 1.0 kg/ha rate, no-till plots contained more and heavier tubers than rotovated plots (Table 6.9). Rao (1968) similarly found that no-till plots contained larger purple nutsedge tubers than cultivated plots, which may be an effect of the tillage practice rather than an effect of glyphosate. Increased tillage would be expected to stimulate tuber sprouting and therefore deplete food reserves.

Purple nutsedge height

Purple nutsedge grew taller in bean than in lettuce during crop cycles 1, 2 and 4 (Table 6.4). Purple nutsedge height increased with crop height (Table 6.10).

The greater height of purple nutsedge in bean plots over that in lettuce plots could be due to; a) the higher level of fertilizer that

Table 6.8. Effect of post harvest application of glyphosate on purple nutsedge tubers after six crop cycles.[xy]

Crop	Number of tubers	Dry weight of tuber
	(tubers/0.1 m^2)	(mg)
clean weeded		
Lettuce	110b	80cd
Lettuce/bean[z]	88b	76cd
Bean	65b	88bc
unweeded		
Lettuce	290a	104ab
Lettuce/bean	320a	77cd
Bean	350a	80cd
glyphosate 0.5 kg/ha		
Lettuce	120b	89abc
Lettuce/bean	120b	83bcd
Bean	95b	97abc
glyphosate 1.0 kg/ha		
Lettuce	77b	65d
Lettuce/bean	64b	91abc
Bean	79b	110a

[x] Average of eight 30 cm by 30 cm and 20 cm deep samples.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

[z] In the lettuce/bean rotation, three cycles of each were planted.

Figure 6.2. Symptoms of glyphosate injury in emerged purple nutsedge after application of glyphosate in the field.

Table 6.9. Effect of rotovation or no-till after post-harvest application of glyphosate at 1.0 kg/ha on purple nutsedge tubers after six crop cycles.[x,y]

Land preparation	Crop	Number of tubers (Tubers/0.1 m^2)	Dry weight of a tuber (mg)
Rotovated	Lettuce	77c	65c
	Lettuce/bean[z]	64c	91bc
	Bean	79c	110b
No-till	Lettuce	95bc	135a
	Lettuce/bean	180a	116ab
	Bean	170a	119ab

[x] Average of eight 30 cm by 30 cm and 20 cm deep samples.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

[z] In the lettuce/bean rotation, three cycles of each were planted.

Table 6.10. Relationship between purple nutsedge height, air temperature and crop height.

X factor	Y factor	r^2	Regression equation
Air temperature	Purple nutsedge height in lettuce	.38**	Y = -16.32 + 1.31X
	Purple nutsedge height in rotation	.36**	Y = -42.59 + 2.48X
	Purple nutsedge height in bean	.36**	Y = -38.82 + 2.44X
Lettuce height	Purple nutsedge height	.41**	Y = 5.95 + 0.75X
Height of rotated crop	Purple nutsedge height	.46**	Y = 9.61 + 0.34X
Bean height	Purple nutsedge height	.46**	Y = -3.90 + 0.68X

** Significant at P=0.01 level.

the bean plots received compared to the lettuce plots; or b) the greater competition by the bean plants; or c) both.

Very little information on the effect of crop interference on purple nutsedge height is available. Increased intraspecific interference resulted in taller purple nutsedge plants (Williams *et al.*, 1977). Although bean plants quickly form a canopy (William and Warren, 1975a), shading purple nutsedge to 15% of full sun did not alter the height of purple nutsedge (Patterson, 1982). However, taller bean plants more likely impose a greater competition on purple nutsedge for light than shorter lettuce plants do. Therefore, the increased height of purple nutsedge could be an effect of greater interference from bean plants.

Purple nutsedge grew taller in summer months than at any other time of the year (Table 6.4). Height of purple nutsedge in lettuce and bean correlated positively with air temperature (Table 6.10). Waimanalo receives 650 u mol/s. m^2 solar radiation during March, 1,000 u mol/s. m^2 during April/June and 1,100 u mol/s. m^2 during June to September[1]. The increased purple nutsedge height in September as compared to June (Table 6.4) in spite of similar radiation levels therefore, is a result of increased temperature rather than an effect due to changes in solar radiation levels.

Information on effect of air temperature on purple nutsedge height is not available. However, increased air temperature

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[1] Lee, C. H. 1978. Genetics of photoperiod sensitivity and seasonal effects in corn (*Zea mays* L.). Ph.D. Dissertation, University of Hawaii, Hi. 96822. pp.223.

increased dry matter production in purple nutsedge with an optimum of 32°C (Wills, 1975; William and Warren 1975a).

Glyphosate as a post harvest treatment reduced the height of purple nutsedge (Tables 6.11, 6.12) (Figures 6.3-6.5), presumably because some sprouted tubers contained glyphosate. Glyphosate is not metabolized in plants including purple nutsedge (Sandberg _et al_., 1980; Wyrill and Burnside, 1976; Zandstra and Nishimoto, 1977). Small amounts of glyphosate reduced height of sorghum (_Sorghum bicolor_ L.) and wheat (_Triticum aestivum_ L.) (Baur _et al_., 1977). Low rates of glyphosate applied to seeds of jointed goatgrass (_Aegilops cylindrica_ Host) and rye (_Secale cereale_ L.) resulted in short plants (Young _et al_., 1984). Therefore, it is possible that some of the sprouted tubers of purple nutsedge contained small amounts of glyphosate and developed into stunted plants.

In every cycle of a given crop, there were no significant differences between purple nutsedge height when glyphosate was used at 0.5 or 1.0 kg/ha (Table 6.11) (Figures 6.3-6.5). Tubers that sprout following glyphosate treatment may contain similar concentrations of herbicide irrespective of the rate used.

Purple nutsedge treated with 1.0 kg/ha glyphosate in no-till plots were shorter than in rotovated plots (Table 6.12) (Figures 6.3-6.5). This could be due to more emerged plants having a low level of glyphosate under the no-till situation. Glyphosate can be re-translocated from previous sinks to newly growing areas (Devine and Bandeen, 1983; Dewey and Appleby, 1983). With no-tillage, the

Table 6.11. Purple nutsedge height following post-harvest application of glyphosate in rotovated plots during six crop cycles.[x,y]

Rate of glyphosate (kg/ha)	Purple nutsedge height — Crop cycle 1	2	3	4	5	6
	-----	-----	(cm)	-----	-----	-----
0	16a	16b	19a	28a	17a	13a
0.5	16a	13b	15b	18b	12b	10b
1.0	17a	13b	14b	17b	11b	10b

[x] Average of four replicates and 10 plants from each replicate.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

Table 6.12. Purple nutsedge height following post-harvest application of glyphosate at 1.0 kg/ha in rotovated and no-till plots during six crop cycles.[x,y]

Land preparation	Purple nutsedge height — Crop cycle 1	2	3	4	5	6
	-----	-----	(cm)	-----	-----	-----
Rotovated	17a	13a	14a	17a	11a	10b
No-till	16a	12b	10b	14b	11a	13a

[x] Average of four replicates and 10 plants from each replicate.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

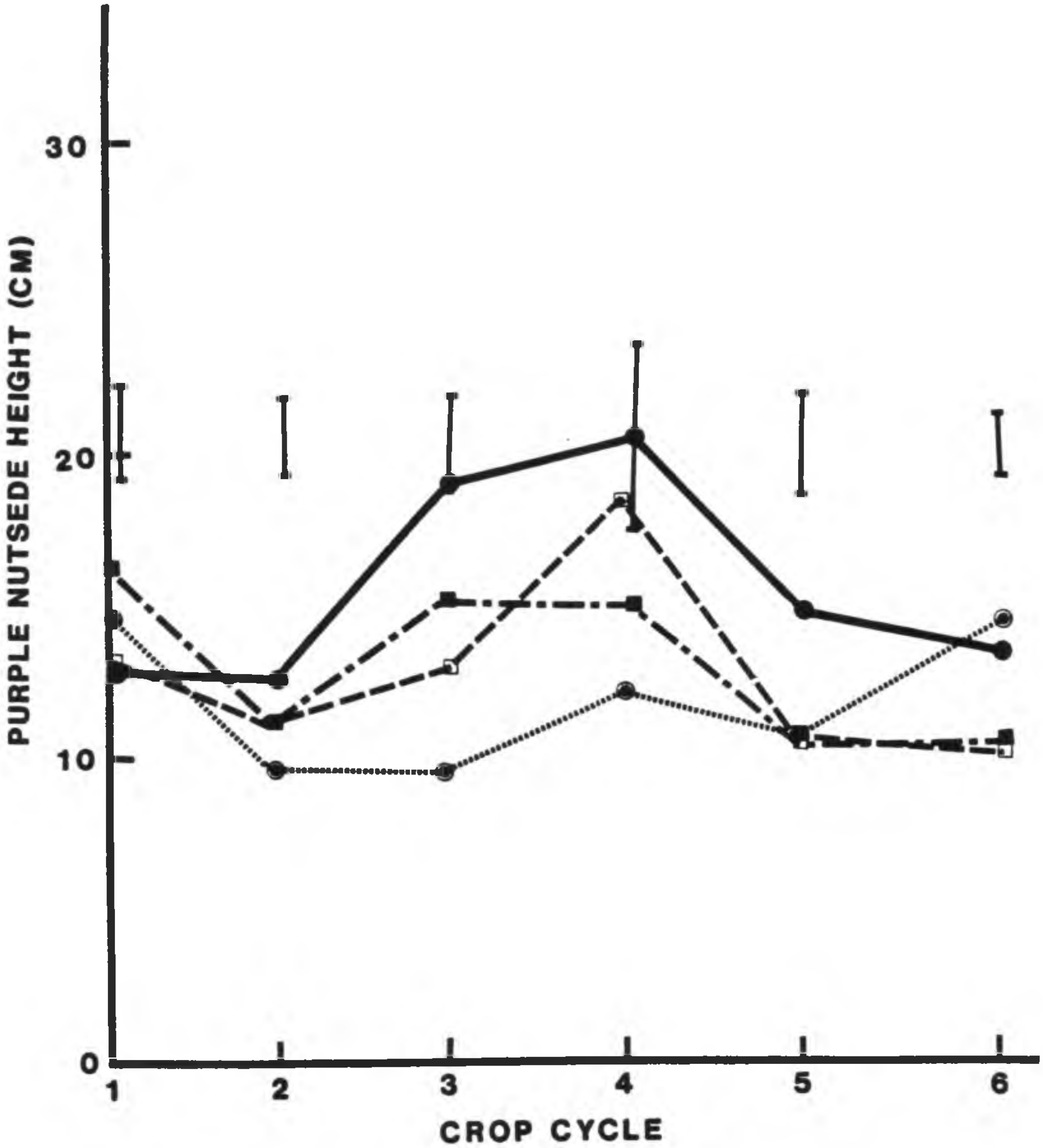

Figure 6.3. Purple nutsedge height in lettuce during the six crop cycles with and without glyphosate. (Average of four replicates). Untreated control (▬▬▬), glyphosate at 0.5 kg/ha (- ▬ - -), 1.0 kg/ha under rotovation (▬ ▬ ▬) and 1.0 kg/ha under no-till (············).

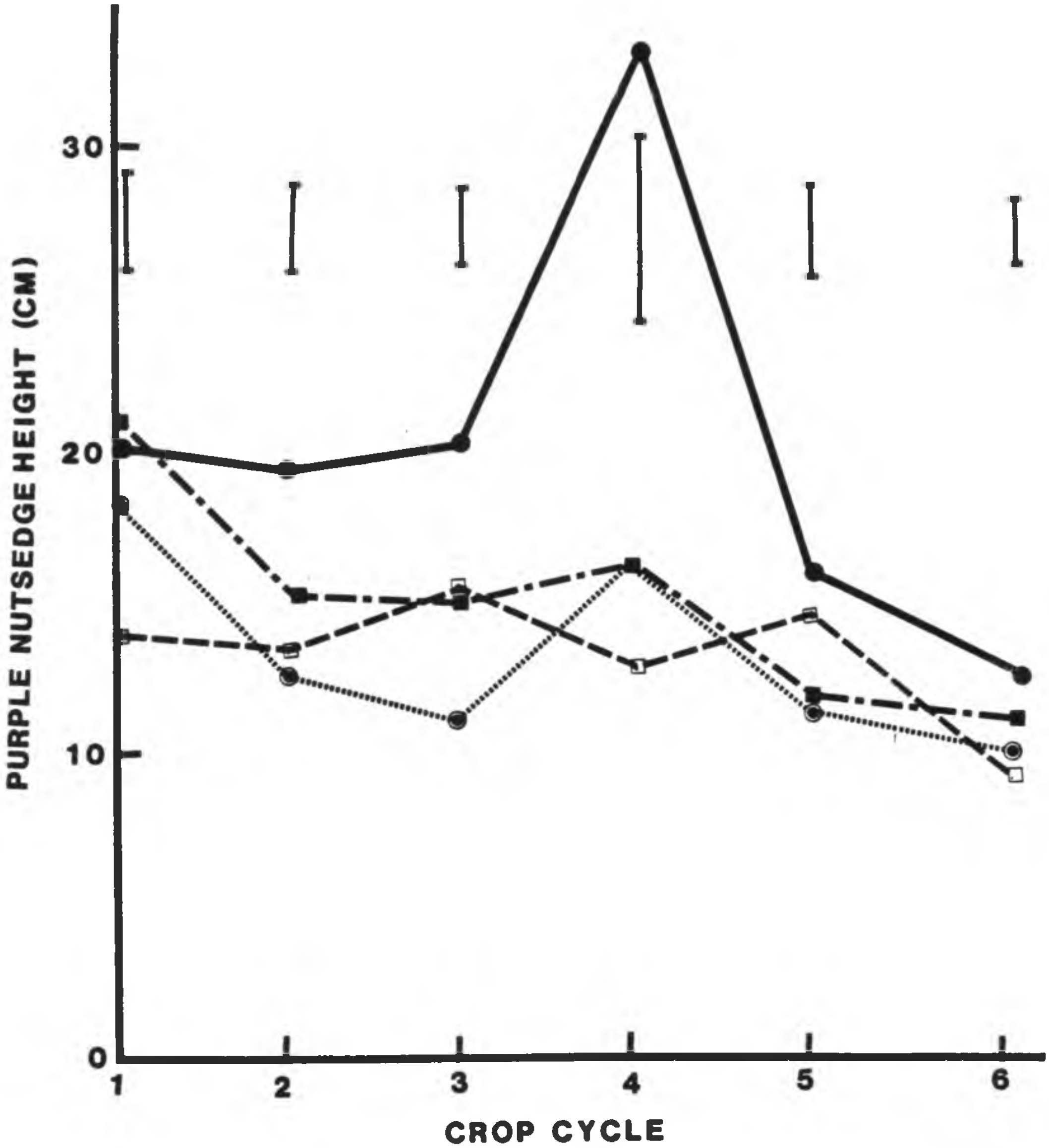

Figure 6.4. Purple nutsedge height in bean during the six crop cycles with and without glyphosate. (Average of four replicates). Untreated control (————), glyphosate at 0.5 kg/ha (—·—), 1.0 kg/ha under rotovation (— — —) and 1.0 kg/ha under no-till (··········).

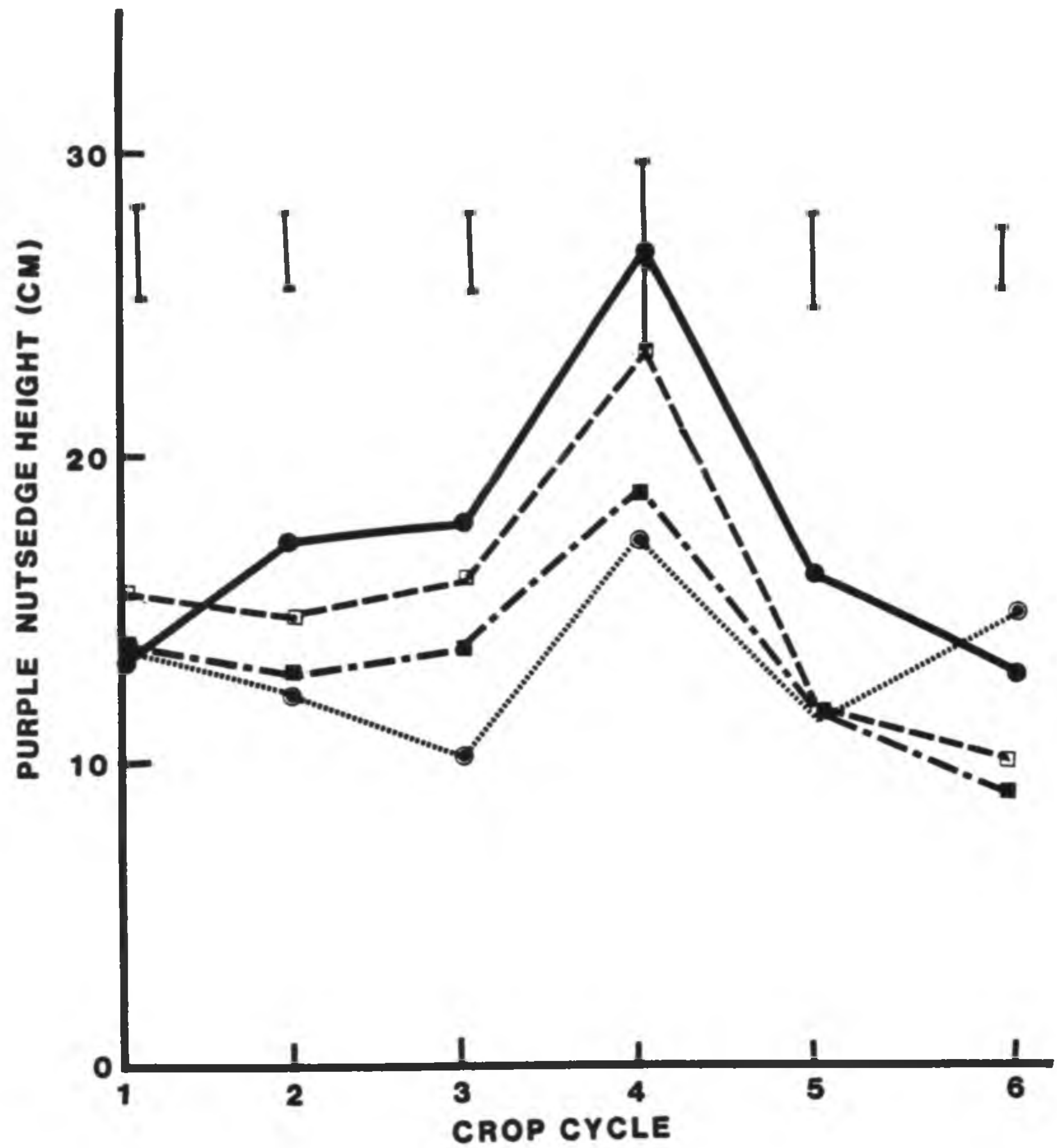

Figure 6.5. Purple nutsedge height in lettuce/bean rotated plots during the six crop cycles with and without glyphosate. (Average of four replicates). Untreated control (▬▬▬), glyphosate at 0.5 kg/ha (-·-·-), 1.0 kg/ha under rotovation (– – –) and 1.0 kg/ha under no-till (··········).

underground plant system was kept undisturbed whereas the tilled system had more broken tuber chains. Therefore, the sprouting tubers, in no-till plots acting as new sinks, could accumulate glyphosate from previous sinks thereby resulting in stunted plants.

Effect of purple nutsedge and its control on crop yields

Effect of purple nutsedge on lettuce

Lettuce did not cover the ground completely in any crop cycle (Figure 6.6). The percent ground cover was different during different crop cycles. The most ground cover occurred during the fifth and the sixth crop cycles. In these crop cycles 50% ground cover occurred between the third and the fourth week after planting. During the first four crop cycles lettuce took about 4 weeks to reach 50% ground cover.

Purple nutsedge plant number, height or volume (volume defined as purple nutsedge plant number/0.1 m^2 x purple nutsedge plant height) did not show a relationship with percent fresh weight reduction of lettuce (Table 6.13). However, these correlated positively with percent dry weight reduction of lettuce. Correlation of percnt dry weight reduction was better with purple nutsedge height and volume than with the number.

Lettuce retained some excess water under weedy conditions, presumably due to a microclimate that was created by the thick mat of purple nutsedge. The formula, fresh weight of lettuce in unweeded plot/dry weight of lettuce in unweeded plot - fresh weight of lettuce in weeded plot/dry weight of lettuce in weeded plot, gives the excess water in unweeded lettuce per unit weight of dry matter. This excess

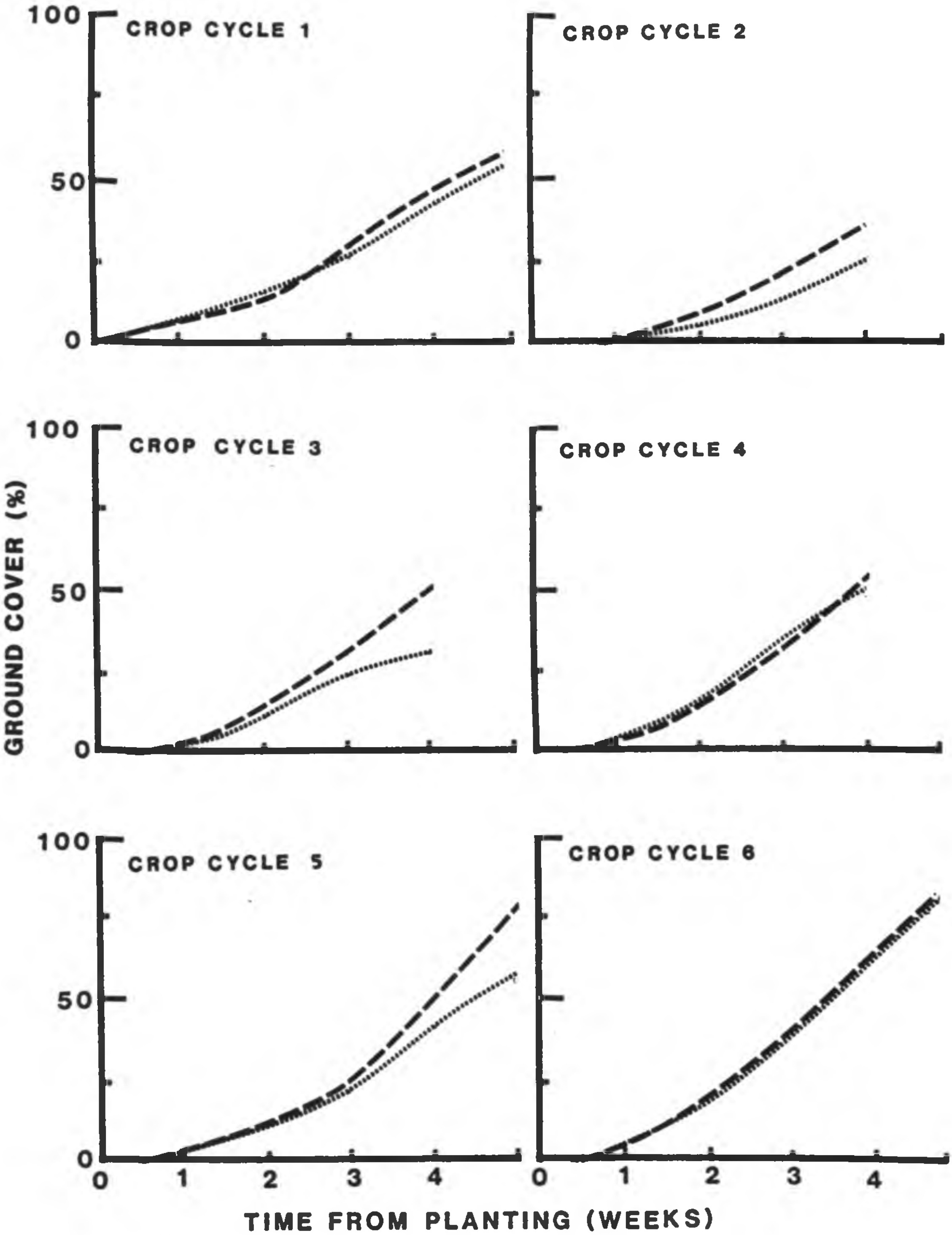

Figure 6.6. Percent ground cover by lettuce during the first 5 weeks of growth in weeded (— — —) and unweeded (..........) plots during the six crop cycles. (Average of four replicates).

Table 6.13. Relationship between percent reduction in fresh weight and dry weight of lettuce and excess water in unweeded lettuce with purple nutsedge.

X factor	Y factor	r^2	Regression equation
Purple nutsedge number	Percent fresh weight reduction	.11	
	Percent dry weight reduction	.17*	Y = 12.63 + 0.34X
	Excess water in unweeded lettuce[x]	.15	
Purple nutsedge height	Percent fresh weight reduction	.04	
	Percent dry weight reduction	.27**	Y =-13.92 + 3.06X
	Excess water in unweeded lettuce	.32**	Y = -4.39 + 0.57X
Purple nutsedge volume[y]	Percent fresh weight reduction	.12	
	Percent dry weight reduction	.32**	Y = 10.26 + 0.02X
	Excess water unweeded lettuce	.32**	Y = 0.40 + 0.004X

[x] Excess water in unweeded lettuce = (Fresh weight of lettuce in unweeded plot/Dry weight of lettuce in unweeded plot) - (Fresh weight of lettuce in weeded plot/Dry weight of lettuce in weeded plot).

[y] Purple nutsedge volume = purple nutsedge number/0.1 m^2 x purple nutsedge height (cm).

* Significant at P=0.05 level.

** Significant at P=0.01 level.

water correlated positively with purple nutsedge height and volume and not with the number. The absence of any relationship between the percent fresh weight reductions and purple nutsedge is likely due to the excess water that lettuce retained under weedy conditions.

Lettuce yielded most fresh weight in crop cycles 1 and 6 (Table 6.14) which corresponded to February and January plantings respectively. The yield declined to a minimum in crop cycles 2 and 3 which corresponded to the June and July plantings respectively. The fresh weight and dry weight of lettuce correlated negatively with the air temperature (Table 6.15).

Purple nutsedge significantly reduced the fresh weight of lettuce in all but crop cycles 1 and 3 (Table 6.14). The fresh weight reductions were 10, 26, 18, 22, 19 and 9% respectively for the six crop cycles. Percent fresh weight reduction appeared greater during the summer months than during the winter months.

Dry weight of lettuce was reasonably uniform in the weeded plots throughout the six crop cycles (Table 6.14). Purple nutsedge reduced the dry weight of lettuce during the warmer period that coincided with the third, fourth and fifth plantings and not during the first, second and the sixth which coincided with the colder period. During the sixth crop cycle, the absence of differences between weeded and unweeded plots could have been due to the shorter purple nutsedge plants and the relatively good growth of lettuce during this coolest period.

Table 6.14. Effect of purple nutsedge on fresh weight, dry weight, fresh weight to dry weight ratio and mean daily dry matter accumulation of lettuce.[xy]

	Fresh weight			Dry weight			Daily dry matter accumulation			Fresh weight/ Dry weight	
Crop cycle	Weeded	Unweeded	Reduction	Weeded	Unweeded	Reduction	Weeded	Unweeded	Reduction	Weeded	Unweeded
	-(kg/7.2m)-		(%)	--(g/7.2m)--		(%)	-(g/day.7.2m)-		(%)		
1	5.7c	5.2c	10	262ab	206bc	21	7.6bc	5.8bcd	16	22cd	25abc
2	3.1fg	2.3h	26	179cd	126cd	29	6.2bcd	4.5d	27	18def	19cde
3	2.4gh	2.0h	18	294a	132cd	55	11.3a	5.0cd	56	9h	16efg
4	4.0de	3.1fg	22	274ab	157cd	42	11.9a	6.8bcd	42	14fgh	19cde
5	4.2d	3.4ef	19	239ab	148cd	38	8.9b	5.0cd	38	17ef	23bc
6	8.7a	7.9b	9	312a	297a	5	7.2bcd	6.9bcd	5	28a	27ab

[x] Average of four replicates.

[y] Means followed by the same letter under fresh weight, dry weight, fresh weight/dry weight or daily dry matter accumulation are not significantly different at P=0.05 by Duncan's mean separation test.

Table 6.15. Relationship between growth and yield of lettuce and bean with air temperature and purple nutsedge height.

		Lettuce		Bean	
X factor	Y factor	r^2	Regression equation	r^2	Regression equation
Air temperature	Fresh weight in unweeded crop	.64**	Y = 26.0 - 0.90X	.25*	Y = 10.0 - 0.62X
	Fresh weight in weeded crop	.62**	Y = 27.0 - 0.01X	.22*	Y = 18.8 - 0.60X
	Dry weight in unweeded crop	.38**	Y = 752 - 23.5X	.10	
	Dry weight in weeded crop	.01		.20	
	Fresh weight to dry weight in unweeded crop	.55**	Y = 69.4 - 1.94X	not conducted	
	Fresh weight to dry weight in weeded crop	.67**	Y = 87.9 - 2.85X	not conducted	
Purple nutsedge height	Crop height	.44**	Y = 3.83 + 0.58X	.46**	Y = 22.6 + 0.68X

* Significant at P=0.05 level.

** Significant at P=0.01 level.

Mean daily accumulation of dry matter in lettuce was greatest when the crop was planted in late June and mid September (Table 6.14). However, lettuce was affected by purple nutsedge most seriously during the same months with reductions of daily dry matter production by 56 and 42% respectively. When planted in January however, the reduction in mean daily dry matter accumulation was only 5%.

Because of the differences in lettuce response to purple nutsedge as measured by fresh or dry weight, comparisions were made for fresh to dry weight ratios (Table 6.14). In crop cycles 3 and 4, lettuce had a lower fresh weight to dry weight ratio than in other crop cycles. This was more apparent in the weeded plots. The fresh weight to dry weight ratio of lettuce and air temperature correlated negatively (Table 6.15). The highest mean air temperatures occurred during crop cycles 3 and 4 (Table 6.7). The greater water content found in unweeded plots could be the result of a possible microclimate formed by purple nutsedge.

Interference with purple nutsedge increased the lettuce height only during the fourth crop cycle or September planting (Table 6.7). However, the crop height in unweeded plots increased with purple nutsedge height and not with the air temperature (Table 6.15).

Effect of glyphosate control of purple nutsedge on lettuce

Post-harvest application of glyphosate followed by rotovation resulted in lettuce yields that were as high as handweeding in all crop cycles (Table 6.16). Inexplicably, no-till treatment with 1.0 kg/ha glyphosate during the fourth crop cycle reduced lettuce yield (1.9 kg/7.2 m row). However, the lettuce dry weight in this treatment was similar to that of handweeding (Table 6.17). Glyphosate did not increase the fresh weight of lettuce over not weeding at any time except during the sixth crop cycle when 1.0 kg/ha glyphosate under no-till was better than no weeding. In this treatment too, the lettuce dry weight was not different from that of the other treatments (Table 6.17).

The absence of differences in lettuce yield as a result of purple nutsedge control during individual crop cycles was probably due to high variability which occurred in the field experiments. However, mean separation with a single degree of freedom showed an advantage in controlling purple nutsedge (Table 6.18). Glyphosate at 1.0 kg/ha increased the lettuce yield over not weeding from the second crop cycle. Although the purple nutsedge stands in plots treated with glyphosate at 0.5 and 1.0 kg/ha were not significantly different (Table 6.3), the reduced purple nutsedge number from that in unweeded plots seemed to have increased the lettuce yield. However, little increase in lettuce yield occurred in the plots treated with glyphosate at 1.0 kg/ha over those treated with glyphosate at 0.5 kg/ha (Table 6.16).

During the fourth crop cycle, glyphosate did not increase the yield of lettuce (Table 6.18). The reasons for this could be the relatively high purple nutsedge emergence (Table 6.4) and its greater

Table 6.16. Effect of post harvest application of glyphosate for purple nutsedge control on fresh weight of lettuce.[xy]

Land preparation	Planting sequence	Crop cycle 1	2	3	4	5	6
		(kg/7.2 m row)					
		clean weeded					
Roto-vated	Continuous	5.8ab	3.1a	2.4a	4.0a	4.2a	8.8bc
	Rotated	5.8ab		2.6a		4.4a	
		unweeded					
	Continuous	5.2bc	2.3a	2.0a	3.1b	3.4a	7.9c
	Rotated	5.4abc		2.0a		3.4a	
		glyphosate 0.5 kg/ha					
	Continuous	5.9a	3.3a	2.9a	3.7ab	4.4a	9.2bc
	Rotated	5.1c		2.6a		4.1a	
		glyphosate 1.0 kg/ha					
	Continuous	5.3abc	3.4a	3.4a	3.8ab	4.6a	9.6b
	Rotated	5.9a		2.2a		4.4a	
No-till	Continuous	5.1c	2.8a	2.5a	1.9c	4.0a	11.3a
	Rotated	5.0c		2.4a		4.2a	

[x] Average of four replicates.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

Table 6.17. Effect of post harvest application of glyphosate for purple nutsedge control on dry weight of lettuce.[x,y]

Land preparation	Planting sequence	Crop cycle 1	2	3	4	5	6
		(g/7.2 m row)					
	clean weeded						
Rotovated	Continuous	263a	178ab	295abc	274a	239a	312a
	Rotated	278a		354a		248a	
	unweeded						
	Continuous	206a	125b	132d	158b	148b	297a
	Rotated	220a		170cd		147b	
	glyphosate 0.5 kg/ha						
	Continuous	244a	203a	262abc	260a	239a	362a
	Rotated	202a		216bcd		209a	
	glyphosate 1.0 kg/ha						
	Continuous	177a	197ab	295abc	242ab	253a	338a
	Rotated	227a		214bcd		219a	
No-till	Continuous	243a	223a	226bcd	196ab	224a	392a
	Rotated	202a		310ab		220a	

[x] Average of four replicates.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

Table 6.18. Mean separation of fresh yield of lettuce by single degree of freedom for selected treatments.

	Continuous crop					Rotated crop	
	Crop cycle					Crop cycle	
Comparison	2	3	4	5	6	3	5
Handweeded/Unweeded	ns	ns	+	ns	ns	ns	ns
Handweeded/ Glyphosate 0.5 kg/ha	ns	ns	ns	ns	ns	ns	ns
Handweeded/ Glyphosate 1.0 kg/ha rotovated	ns	ns	ns	ns	ns	ns	ns
Handweeded/ Glyphosate 1.0 kg/ha no-till	ns	ns	-	ns	ns	ns	ns
Unweeded/ Glyphosate 0.5 kg/ha	ns	ns	ns	+	ns	ns	ns
Unweeded/ Glyphosate 1.0 kg/ha rotovated	+	+	ns	+	ns	ns	+
Unweeded/ Glyphosate 1.0 kg/ha no-till	ns	ns	-	ns	ns	ns	ns
Glyphosate 1.0 kg/ha rotovated/Glyphosate 1.0 kg/ha no-till	ns	ns	-	ns	ns	ns	ns

ns Not significantly different at P=0.05.

+ or - indicates a significant increase or decrease in yield respectively in the second factor over the first at P=0.05.

height during this period (Figures 6.3-6.5) than at other times of the year.

Handweeding was not superior to no weeding except during crop cycle 4 (Table 6.18). It is possible that some interference by purple nutsedge occurred in between the two weedings of the handweeded plots resulting in a reduced yield.

Post harvest application of glyphosate resulted in dry weight of lettuce equal to that of handweeded plots during all seasons (Table 6.17). However, any superiority over not weeding occurred only during the fifth crop cycle.

Regression analyses of lettuce yield for each crop cycle did not show any relationship between the fresh weight of lettuce and purple nutsedge plant number, height or volume. However, lettuce dry weight showed a negative linear regression with purple nutsedge plant number and volume in all but the sixth crop cycle (Table 6.19).

Purple nutsedge height showed significant relationships with lettuce yields only during crop cycles one, two and five. During crop cycles one and two, purple nutsedge stand in the plots was high. As the purple nutsedge population was generally decreasing due to the use of glyphosate, this linear relationship disappeared. Therefore, the use of purple nutsedge height appears to be applicable only when the plant density is high.

Effect of purple nutsedge on bean

Bean usually achieved a 50% ground cover between 2 and 3 weeks after planting (Figure 6.7). Almost 100% ground cover was achieved in about 5 weeks after planting in most crop cycles, although during

Table 6.19. Relationship between dry weight of lettuce and purple nutsedge.

Crop cycle	X factor (Purple nutsedge)	r^2	Regression equation
1	Number	.08	
	Height	.25**	Y = 340 - 8.68 X
	Volume[x]	.18*	Y = 243 - 0.03 X
2	Number	.44**	Y = 236 - 1.78 X
	Height	.26*	Y = 399 - 19.0 X
	Volume	.48**	Y = 230 - 0.13 X
3	Number	.22**	Y = 267 - 1.71 X
	Height	.04	
	Volume	.19*	Y = 260 - 0.08 X
4	Number	.30*	Y = 256 - 1.90 X
	Height	.02	
	Volume	.28*	Y = 249 - 0.08 X
5	Number	.27**	Y = 232 - 0.827X
	Height	.26**	Y = 346 - 11.23X
	Volume	.27**	Y = 228 - 0.047X
6	Number	.08	
	Height	.01	
	Volume	.06	

[x] Volume = Purple nutsedge plant number/0.1 m^2 x Purple nutsedge plant height (cm).

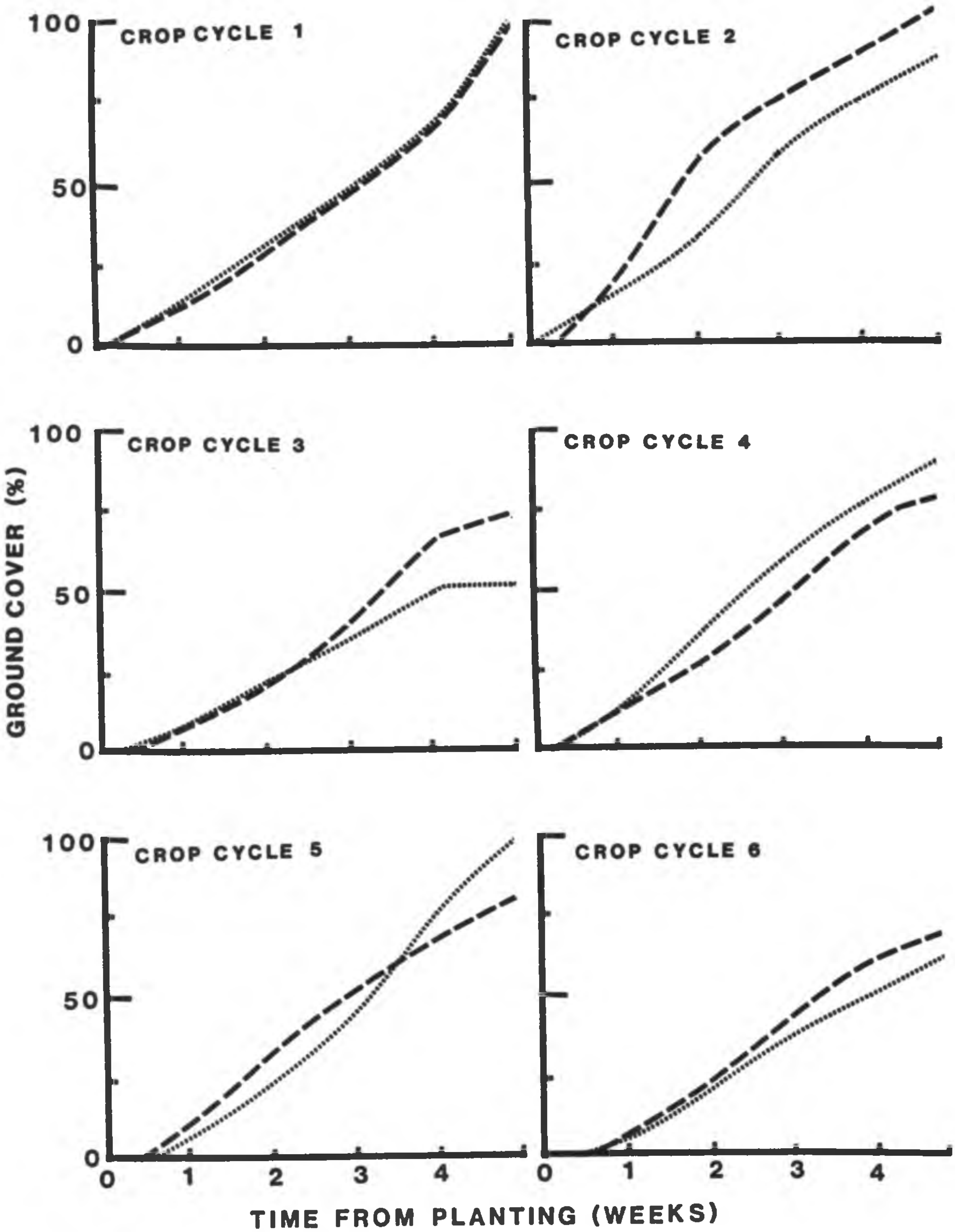

Figure 6.7. Percent ground cover by bean during the first 5 weeks of growth in weeded (— — —) and unweeded (··········) plots during the six crop cycles. (Average of four replicates).

the third and the sixth crop cycles, bean never covered the ground fully. Bean appeared to be able to cover the ground under unweeded conditions as well as under hand-weeded conditions.

Bean yielded least when planted in late June and most when planted in April (Table 6.20). The fresh weight of pods correlated negatively with the air temperature (Table 6.15).

Purple nutsedge did not affect the fresh weight of bean pods or the dry weight of bean leaves and stems (Table 6.20). However, bean height correlated positively with purple nutsedge height (Table 6.15). The absence of effect on bean yield by purple nutsedge is in agreement with William and Warren (1975a) who classified bean as a competitive crop with purple nutsedge.

Effect of purple nutsedge control on bean

Control of purple nutsedge did not alter the fresh weight of bean pods (Table 6.21). However, during the sixth crop cycle, plots rotated with lettuce yielded more than those planted with continuous bean except in the unweeded plots.

Continuous planting of a single crop in one location is known to be detrimental to the crop due to many reasons such as the build up of plant-parasitic nematodes (Good, 1972), soil-borne pathogens (Zentmyer and Bald, 1977), insects (Luckmann, 1978) and autotoxicity from crop residues and root exudates (Bonner, 1960). Although the bean plants looked healthy during the sixth crop cycle, some of the above factors may have been responsible for the reduced yield of bean pods in the continuously planted plots as compared to the rotated plots.

Table 6.20. Effect of purple nutsedge on fresh weight of bean pods and dry weight of bean leaves and stems.[xy]

Crop cycle	Fresh weight of pods: Weeded	Fresh weight of pods: Unweeded	Fresh weight of pods: Reduction	Dry weight of leaves and stems: Weeded	Dry weight of leaves and stems: Unweeded	Dry weight of leaves and stems: Reduction
	(kg/7.2 m row)		(%)	---(g/m row)---		(%)
1	4.8bc	4.5bc	6	107a	109a	-2
2	8.1a	7.5a	7	116a	91a	21
3	1.2e	0.7e	41	60b	41b	31
4	2.3d	2.2d	4	50b	47b	6
5	3.6bcd	3.0cde	17	36b	40b	-11
6	5.3b	5.3b	0	45b	45b	10

[x] Average of four replicates.

[y] means followed by the same letter under fresh weight of pods or dry weight of leaves and stems are not significantly different at P=0.05 by Duncan's multiple range test.

Table 6.21. Effect of post harvest application of glyphosate for purple nutsedge control on fresh weight of bean pods.[x]

Land preparation	Planting sequence	Fresh weight of pods — Crop cycle 1	2	3	4	5	6
		(kg/7.2 m row)					
	clean weeded						
Rotovated	Rotated		18.7a		6.3a		15.6a
	Continuous	10.7a	18.0a	2.7a	5.1a	8.2a	11.7cd
	unweeded						
	Rotated		18.8a		7.0a		11.8cd
	Continuous	9.9a	16.7ab	1.6a	4.9a	6.7a	11.7cd
	glyphosate 0.5 kg/ha						
	Rotated		18.7a		6.2a		15.0ab
	Continuous	10.0a	16.4ab	1.7a	3.4a	7.8a	9.7de
	glyphosate 1.0 kg/ha						
	Rotated		16.4ab		5.5a		15.8a
	Continuous	9.8a	17.0ab	1.3a	3.5a	7.5a	10.8cd
No-till	Rotated		12.6c		5.5a		13.6abc
	Continuous	9.1a	14.6bc	1.6a	4.6a	5.8a	7.3e

[x] Average of four replicates.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

The dry weight of bean leaves and stems did not change with purple nutsedge control (Table 6.22). However, during the sixth crop cycle, increased dry weight of leaves and stems in crop rotated plots compared to the continuously planted plots occurred that was comparable to the fresh weight increases in pods (Table 6.21).

Mean separation by a single degree of freedom also showed that control of purple nutsedge in bean did not increase yield compared to no weeding.

Conclusion

Glyphosate applied post harvest at 0.5 and 1.0 kg/ha under rotovation or 1.0 kg/ha under no-till reduced purple nutsedge emergence and height in lettuce and bean. Use of glyphosate was as good as hand weeding during six crop cycles in reducing purple nutsedge tubers in the soil. Interference by purple nutsedge did not reduce the yield of lettuce when the mean daily minimum and maximum air temperature was between 18 and 26 to 22 and 28 C respectively. However above these temperatures, interference by purple nutsedge reduced the fresh weight, dry weight and mean daily dry matter accumulation of lettuce. The yield reduction was related to height of purple nutsedge and therefore possibly due to competition for light. Purple nutsedge height correlated positively with air temperature. Hence, purple nutsedge control in 'Manoa' lettuce is only necessary during hot weather or when purple nutsedge grows tall.

Glyphosate at 1.0 kg/ha increased the lettuce yield over no weeding from the second crop cycle. However in September, when purple nutsedge grew 20 cm tall with a population of 18 plants/0.1

Table 6.22. Effect of post harvest application of glyphosate for purple nutsedge control on dry weight of bean leaves and stem.[xy]

Land preparation	Planting sequence	Crop cycle 1	2	3	4	5	6
		(g/m row)					
		clean weeded					
Rotovated	Rotated		105a		42a		73ab
	Continuous	107a	116a	60a	50a	36a	50b
		unweeded					
	Rotated		93a		49a		54b
	Continuous	109a	91a	41a	47a	40a	45b
		glyphosate 0.5 kg/ha					
	Rotated		97a		48a		73ab
	Continuous	105a	91a	55a	52a	50a	49b
		glyphosate 1.0 kg/ha					
	Rotated		103a		63a		84a
	Continuous	97a	102a	51a	40a	44a	54b
No-till	Rotated		87a		47a		67ab
	Continuous	105a	69a	52a	41a	48a	60ab

[x] Average of four replicates.

[y] Means in a column followed by the same letter are not significantly different at P=0.05 by Duncan's multiple range test.

m^2, even this rate of glyphosate was ineffective to increase lettuce yield.

Fresh weight of bean pods or dry weight of bean leaves and stems was not affected by interference with purple nutsedge. Furthermore, under these experimental conditions, control of purple nutsedge by the glyphosate treatments in green bean 'Green Crop' did not result in increased yield.

CHAPTER VII

DISCUSSION AND CONCLUSION

Low levels of glyphosate in plants act like hormones (Baur, 1979). Low levels of glyphosate increased plant fresh weight, dry weight and height (Coupland and Caseley, 1975; Baur *et al*., 1977; Young *et al*., 1984). By interfering with apical dominance, glyphosate also caused basal bud sprouting in quackgrass, sorghum and wheat (Coupland and Caseley, 1975; Baur, 1979). In purple nutsedge, increased tuber production at the first basal bulb occurred in plants treated with glyphosate (Chapter V). Occasional increases in percent tuber sprouting occurred in the pot experiments with 0.25 kg/ha glyphosate (Chapter V). Therefore, it appears that glyphosate at a very low level promotes growth and tuber sprouting of purple nutsedge and may increase rather than reduce population.

At 0.5 kg/ha and higher, glyphosate inhibited tuber sprouting of purple nutsedge (Chapter V). Similar inhibition of tuber sprouting has been reported by Chase and Appleby (1979b), Doll and Piedrahita (1982), Magambo and Terry (1973) and Toth and Smith (1979). Doll and Piedrahita (1982) determined by the tetrazolium chloride test that tubers that did not sprout after 6 months were dead. Magambo and Terry (1973) sampled tubers 6 months after a field application of glyphosate and found that tubers that did not sprout in 5 days were alive by the tetrazolium chloride test. However, the short time of incubation does not clearly indicate if these tubers were capable of sprouting with an increased incubation period.

In the experiments reported herein, some tubers, particularly the newly developing ones, were visibly dead within 2 weeks of glyphosate application. They did not sprout in petri dishes and disintegrated within 3 to 4 weeks.

Therefore, it appears that purple nutsedge tubers respond to glyphosate in three ways, probably depending on concentration in the tuber: 1) increased tuber sprouting at very low levels, 2) inhibition of tuber sprouting without immediate kill at intermediate concentrations, and 3) immediate death of tuber due to a high concentration in the tuber.

The re-infestation of fields by purple nutsedge after application of glyphosate has been attributed to the unsprouted tubers at time of treatment (Doll and Piedrahita, 1982; Magambo and Terry, 1973; Toth and Smith, 1979). This may be partly true, as a 6 week old stand of purple nutsedge contained 30% of parent tubers that did not produce new plants (Chapter IV). This amounted to 750 tubers/m^2. However, the results described in Chapter III showed that all the tubers attached to a treated plant are not equally affected by glyphosate and some sprout and produce tubers.

The least affected types of tubers by glyphosate viz, the basal bulbs and chains of two tubers amounted to 41% of the total population at 6 weeks. Chains of more than two tubers were not tested. However, it is less likely that these tubers will be affected greatly by treatments of glyphosate to the differential accumulation of glyphosate. Considering chains of two or more than two tubers, it is estimated that 67% of the tubers are not greatly affected by glyphosate applied at 6 weeks after the tillage operations have been completed.

Magambo and Terry (1973) conducted their experiment in the field using up to 6.0 kg/ha glyphosate. With 5 days of incubation, they observed 20% tuber sprouting at 2.0 kg/ha glyphosate and 12% sprouting at 6.0 kg/ha. Doll and Piedrahita (1982) conducted their experiments in pots with plants originating from single tubers. They obtained a higher glyphosate activity than Magambo and Terry (1973) did, with only 10% and 0% of the tubers sprouting at 2.0 and 4.0 kg/ha glyphosate respectively after 6 months of incubation. Likewise greater inhibition of tuber sprouting occurred in pots than in the field in the experiments reported here.

Clearly, field applications of glyphosate are less effective than pot applications. The reason for this difference may be due to differences in tuber status in the two situations combined with the translocation pattern of glyphosate in purple nutsedge.

In the pot experiments, all the tubers except the planted tuber were from the new generation of plants. No dormant tubers were found. Hence all of the tubers were either actively growing new tubers or those with leaves. However, in the field, 51% of the total tubers were from the parent generation of plants. Thus 51% of the tubers did not have leaves or direct aerial exposure.

Accumulation of glyphosate occurs primarily in the actively growing meristematic regions of the plants (Devine and Bandeen, 1983; Haderlie _et al_., 1976; Sandberg _et al_., 1980; Zandstra and Nishimoto, 1977). In 6 week old purple nutsedge, most accumulation of glyphosate was in the growing leaves and newly developing tubers (Zandstra and Nishimoto, 1977). As a result of translocation of glyphosate to selected tubers, little effect on other tubers can be expected. This was seen in our experiments in which the parent tubers and even the basal bulbs through which glyphosate was translocated showed little damage by glyphosate (Chapter III).

Although Magambo and Terry (1973) did not catagorize tubers in their report, they found more sprouting in tubers from the deeper soil layers than from the first 10 cm layer of soil. Tubers deeper in the soil are more likely to be those from the parent population as most of the new tubers develop near the soil surface. Therefore, Magambo and Terry (1973) may have sampled mostly parent tubers from deeper layers of soil.

Therefore, the inability of glyphosate to eradicate purple nutsedge must be partly due to the ability of some tubers of treated plants to sprout and establish new plants. This was observed in experiments when the sprouted tubers of treated plants produced new tubers when grown in pots (Chapter III). Also in the field, purple nutsedge that grew following post-harvest application of glyphosate were stunted presumably because of glyphosate (Chapter VI).

Increased inhibition of tuber sprouting occurred in June and October than compared to March (Chapter III). Glyphosate closely follows the pathway of photoassimilates (Devine and Bandeen, 1983; Dewey and Appleby, 1983). Purple nutsedge has a C-4 photosynthetic pathway and optimum temperature for its growth is 32 C (William and Warren, 1975a; Wills, 1975). Daily mean minimum and maximum temperatures in our field experiments were 23 and 31 C respectively in June/October and 18 and 26 C respectively in March (Chapter III). Therefore, the increased temperature during June and October may have increased the rate of photosynthesis and caused increased flow of photoassimilates to the parent tubers for storage. This would have caused more transport of glyphosate to parent tubers during June and October than in March. In March, the low temperature may have reduced the rate of photosynthesis and hence, most of the photoassimilates may have been directed for production of new tubers rather than for storage. This would explain the ineffectiveness of glyphosate on the parent tubers in March.

Alternatively, the loss of apical dominance caused by glyphosate could re-direct accumulated glyphosate from the terminal tubers to the basal bulbs of purple nutsedge. It is also possible that the newly developing tubers were killed by glyphosate faster in June and October than in March due to the high temperature. As a result, basal bulbs and parent tubers may have acted as new sinks for photoassimilates thus receiving glyphosate faster in June and October than in March. This is evident by the reduction of sprouting of basal bulbs after 8 days of exposure in June as compared with 16 days in March 1984 (Chapter III). The absence of sprouting inhibition of basal bulbs in March 1985, after 16 days of glyphosate exposure also may have been a result of slightly lower temperature in March 1985 than in March 1984.

Therefore, it can be concluded that field application of glyphosate does not eradicate purple nutsedge at 1.0 or 2.0 kg/ha, but better control can be expected during warm weather than during cold weather.

Repeated application of glyphosate or high rates of glyphosate did not eradicate purple nutsedge. Use of such methods may be less economical to the user. However, 0.5 and 1.5 kg/ha glyphosate have reduced field populations of glyphosate (Doll and Piedrahita, 1982). In pot experiments, 0.5 kg/ha glyphosate was sufficient to reduce the percent tuber sprouting (Chapter V).

Crops have varying degrees of yield losses due to interference of purple nutsedge (William and Warren, 1975a). Generally, those that form a canopy in a short time suffer a lesser yield loss than those that do not.

Lettuce was shorter than purple nutsedge during the summer months and did not cover the ground completely (Chapter VI). Bean was always taller than purple nutsedge and covered the ground completely from the third and fourth week after planting, and was more tolerant to purple nutsedge interference than lettuce.

Lettuce had lower fresh weight, dry weight and mean daily dry matter accumulation during the summer months as a result of interference with purple nutsedge (Chapter VI). Purple nutsedge did not reduce the bean yield at any time. Based on these results, management of purple nutsedge in crops seems unnecessary unless it grows taller than the crop or when the crop does not completely cover the ground within a short time provided nutrients and water are non-limiting.

Glyphosate at 1.0 kg/ha as a post-harvest treatment reduced purple nutsedge stand and precluded the lettuce yield losses to purple nutsedge (Chapter VI). Although management of purple nutsedge during winter months seems unnecessary in lettuce, early management of purple nutsedge may be advisable so that summer populations of purple nutsedge do not decrease lettuce yields.

Purple nutsedge does not grow well under shade. Therefore, one could expect a lower population of this weed in bean, after six crop cycles. However, in spite of the rapid ground cover by bean, the purple nutsedge density or the tuber number in bean plots were unaffected (Chapter VI). The bean crop generally took about 8 weeks to complete. The crop covered the ground completely for about 5 weeks. The experiment was conducted for 57 weeks. Therefore, the ground was covered only about 25 weeks. Leaving approximately one week from each crop cycle for land preparation 57 weeks - (25 weeks + 5 weeks) = 27 weeks (47% of the growing period) were available for purple nutsedge with full or partial cover. Therefore, it seems unlikely that a short-term crop that forms a canopy for only a short time will reduce the purple nutsedge population.

LITERATURE CITED

Anderson, R. N. 1968. Germination and establishment of weeds for experimental purposes. Weed Science Society, Urbana, Illinois 236 pp.

Andrews, F. W. 1940. A study of nutgrass (Cyperus rotundus L.) in the cotton soil of Gezira. The maintenance of life in the tuber. Annals of Botany 4:177-193.

Antognini, J., D. F. Dye, G. F. Probandt and R. Curtis. 1959. Control of quackgrass and nutgrass in horticulture and agronomic crops with Eptam (EPTC). Proceedings North Central Weed Control Conference 13:50-51.

Appleby, A. P. and E. C. Paller. 1978. Effect of naptalam on growth of yellow nutsedge and subsequent control with glyphosate. Weed Research 18:247-253

Baird, D. D., R. P. Upchurch, W. B. Homesly and J. E. Franz. 1971. Introduction of a new broad spectrum post emergence herbicide class with utility for herbaceous perennial weed control. Proceedings North Central Weed Control Conference 29:64-68.

Baker, R. S. 1964. Reproductive capacity of nutsedge (Cyperus rotundus) tubers. Abstracts Weed Science Society of America p.63.

Baur, J. R. 1979. Reduction of glyphosate induced tillering of sorghum (Sorghum bicolor) by several chemicals. Weed Science 27:69-73.

Baur, J. R., R. E. Bovey and J. A. Veech. 1977. Growth responses in sorghum and wheat induced by glyphosate. Weed Science 25:238-240.

Berger, G. and B. E. Day. 1967. Dormancy, growth inhibition, and tuberization of nutsedge (Cyperus rotundus) as affected by photoperiods. Proceedings Asian-Pacific Weed Science Society 1:123.

Boldt, P. F. and R. D. Sweet. 1974. Glyphosate studies in yellow nutsedge. Proceedings NorthEastern Weed Science Society 28:197-204

Bonner, H. 1960. Liberation of organic substances from higher plants and their role in the soil sickness problem. Botanical Review 26:393-424.

Burgis, D. S. 1969. Phytotoxicity of purple nutgrass (Cyperus rotundus L.) and soil persistence of some hormone type herbicides and tillage. Proceedings Southern Weed Science Society 8:405-408.

Chase, R. L. and A. P. Appleby. 1979a. Effect of humidity and moisture stress on glyphosate control of Cyperus rotundus L. Weed Research 19:241-246.

Chase, R. L. and A. P. Appleby. 1979b. Effect of intervals between application and tillage of glyphosate control of Cyperus rotundus L. Weed Research 19:207-211.

Claus, J. S. and R. Behrens. 1976. Glyphosate translocation and quackgrass rhizome bud kill. Weed Science 24:149-152.

Cools, W. G. and S. J. Locascio. 1977. Influence of nutrition and temperature on the germination rate of purple nutsedge (Cyperus rotundus L.). Abstracts Weed Science Society of America #164.

Coupland, D. D. and J. C. Caseley. 1975. Reduction of silica and increase in tillering induced in Agropyron repens by glyphosate. Journal of Experimental Botany 26:138-144.

Davis, C. H. 1942. Response of Cyperus rotundus L. to five moisture levels. Plant Physiology 17:311-316.

Devine, M. D. and J. D. Bandeen. 1983. Fate of glyphosate in Agropyron repens L. Beauv. growing under low temperature conditions. Weed Research 23:69-75.

Dewey, S. A. and A. P. Appleby. 1983. A comparison between glyphosate and assimilate translocation patterns in tall morningglory (Ipomoea purpurea). Weed Science 31:308-314.

Doll, J. D. and W. Piedrahita. 1982. Effect of glyphosate on the sprouting of Cyperus rotundus L. tubers. Weed Research 22:123-128.

Good, J. M. 1972. Bionomics and integrated control of plant parasitic nematodes. Journal of Environmental Quality 1:382-386.

Haderlie, L. C., H. S. Butler and F. W. Slife. 1976. Absorption and translocation of glyphosate in soybeans - Plants and germinating seeds. Abstracts Weed Science Society of America #188.

Hamilton, K. C. 1971. Repeated foliar application of MSMA on purple nutsedge. Weed Science 19:675-677.

Hammerton, J. L. 1968. Nutgrass in Panama: First impression. PANS. 14:339-345.

Hammerton, J. L. 1974. Experiments with Cyperus rotundus L. I. Growth and development effects of 2,4-D and paraquat. Weed Research 14:365-370.

Hammerton, J. L. 1975. Experiments with Cyperus rotundus L. III. Seasonal variation in growth. Weed Research 15:339-348.

Hauser, E. W. 1962. Development of purple nutsedge under field conditions. Weeds 10:315-321.

Hauser, E. W. 1963. Response of purple nutsedge to amitrole, 2,4-D and EPTC. Weeds 11-251-252.

Holm, L. R. G., D. L. Plucknett, J. V. Pancho and J. P. Herberger. 1977. Pages 8-24 In The Worlds Worst Weeds. Distribution and Biology. The University Press of Hawaii, Honolulu.

Horowitz, M. 1972. Growth, tuber formation and spread of Cyperus rotundus L. from single tubers. Weed Research 12:348-363.

Jangaard, B. J., M. M. Sckrel and R. H. Schieferstein. 1971. The role of phenolics and abscisic acid in nutsedge tuber dormancy. Weed Science 19:17-20.

Justice, O. L. and M. D. Whitehead. 1946. Seed production, viability and dormancy in the nutgrass Cyperus rotundus and C. esculentus. Journal of Agricultural Research 73:303-318.

Keeley, P. E. and R. J. Thullen. 1971. Control of nutsedge with organic arsenical herbicides. Weed Science 19:601-606.

Keeley, P. E. and R. J. Thullen. 1978. Light requirements of yellow nutsedge (Cyperus esculentus) and light interception by crops. Weed Science 26:10-16.

Keeley, P. E., R. J. Thullen, J. H. Miller and C. H. Carter. 1979. Comparision of four cropping systems for yellow nutsedge (Cyperus esculentus) control. Weed Science 27:463-467.

Klevorn, T. B. and D. L. Wyse. 1984. Effect of soil temperature and moisture on glyphosate and photoassimilate distribution in quackgrass (Agropyron repens). Weed Science 32:402-407.

Klevorn, T. B. and D. L. Wyse. 1985. Effect of leaf girdling and rhizome girdling on glyphosate transport in quackgrass (Agropyron repens). Weed Science 33:744-750.

Klosterboer, A. D. 1974. Phytotoxicity of glyphosate and paraquat to bearing citrus. Proceedings Southern Weed Science Society 27:166-169.

Koogan, M. and M. I. Gonzalez. 1979. Yellow and purple nutsedge vegetative propagule production and the effect of MSMA and glyphosate. Proceedings Western Society of Weed Science 32:87-92.

Linscott, D. L. and R. D. Hagin. 1973. Comparisons of glyphosate and paraquat for nutsedge control prior to seeding of alfalfa. Proceedings NorthEastern Weed Science Society 27:8.

Luckmann, W. H. 1978. Insect control in corn-practices and prospects. Pages 137-155 In E. H. Smith and D. Pimentel (Eds), Pest control strategies. Academic Press, New York.

Magambo, M. J. S. and P. J. Terry. 1973. Control of purple nutsedge (Cyperus rotundus) with glyphosate. Proceedings Asian-Pacific Weed Science Society 4:191-194.

Martinez, E. and E. Pulver. 1975. Effecto de applicaciones repetidas de glifosoto en el control de Cyperus rotundus L. en algunos frutales. Rev. Ala. 2:12-23. (From Weed Research 22:123-128).

McAllister, R. S. and L. C. Haderlie. 1985. Translocation of ^{14}C-glyphosate in Canada thistle (Cirsium arvense). Weed Science 33:153-159.

Mosavi-Nia, H. and J. Dore. 1979. Factors affecting glyphosate activity in Imperata cylindrica L. Beauv. and Cyperus rotundus L. I. Effect of soil moisture. Weed Research 19:137-143.

Muzik, T. J. and H. J. Cruzado. 1950. The effects of 2,4-D on sprout formation of Cyperus rotundus. American Journal of Botany 40:507-512.

Okafor, L. I. and S. K. De Datta. 1976. Competition between upland rice and purple nutsedge for nitrogen, moisture and light. Weed Science 24:43-46.

Parker, C., K. Holly and S. D. Hocombe. 1969. Herbicides for nutgrass control--conclusions from ten years of testing at Oxford.. PANS 15:54-63.

Patterson, D. T. 1982. Shading responses of purple and yellow nutsedge (Cyperus rotundus and C. esculentus). Weed Science 30:25-30.

Ranade, S. B. and W. Burns. 1925. The eradication of Cyperus rotundus L. India Department of Agriculture Memoirs Botany 13:99-192.

Rao, J. S. 1968. Studies on the development of tubers in nutgrass and their starch content at different depths of soil. Madras Agricultural Journal 55:18-23.

Ray, B. and M. Wilcox. 1969. Chemical fallow control of nutsedge. Weed Research 9:86-94.

Sandberg, C. L., W. L. Meggitt and D. Penner. 1980. Absorption, translocation and metabolism of ^{14}C glyphosate in several weed species. Weed Research 20:195-196.

Sinha, T. and E. Thakur. 1967. Control of nutgrass weed by cultivation. Indian Journal of Agronomy 12:121-125.

Smid, D. and L. K. Hiller. 1981. Phytotoxicity and translocation of glyphosate in potato (Solanum tuberosum) prior to tuber initiation. Weed Science 29:218-223.

Smith, E. V. and G. L. Fick. 1937. Nutgrass eradication studies: I. Relation of the life history of nutgrass, Cyperus rotundus L., to possible methods of control. American Society of Agronomy Journal 29:1007-1013.

Smith, E. V. and E. L. Mayton. 1938. Nutgrass eradication studies: II. The eradication of nutgrass, Cyperus rotundus L. by certain tillage treatments. American Society of Agronomy Journal 30:18-21.

Smith. E. V. and E. L. Mayton. 1942. Nutgrass eradication studies: III. The control of nutgrass, Cyperus rotundus L., on several soil types by tillage. American Society of Agronomy Journal 34:151-159.

Standifer, L. C. 1974. Control of purple nutsedge with 2,4-D, paraquat, and dinoseb. Weed Science 22:520-522.

Standifer, L. C. 1980. Control of purple nutsedge with repeated glyphosate application. Proceedings Southern Weed Science Society 33:297.

Suwunnamek, U. and C. Parker. 1975. Control of Cyperus rotundus L. with glyphosate:the influence of ammonium sulphate and other additives. Weed Research 15:13-19.

Tarawanich, T. and D. L. Linscott. 1975. Factors influencing the effect of glyphosate on yellow nutsedge. Proceedings NorthEastern Weed Science Society 29:132.

Teo, C. H. K. and R. K. Nishimoto. 1973. Cytokinin enhanced sprouting of purple nutsedge as a basis for control. Weed Research 13:118-121.

Teo, C. K. H., R. K. Nishimoto and C. S. Tang. 1974. Bud inhibition of Cyperus rotundus L. tubers by inhibitor B or abscisic acid and the reversal of these by N-6-benzyl adenine. Weed Research 14:173-179.

Thompson, J. T. and J. W. Daniel. 1974. Effectiveness of basangrass with air and ground application. Proceedings Southern Weed Science Society 26:74-76.

Toth, J. and L. W. Smith. 1979. Cyperus rotundus control with glyphosate. Proceedings Asian-Pacific Weed Science Society 7:67-69.

Tripathi, R. S. 1969. Ecology of Cyperus rotundus L. III. Population of tubers at different depths of the soil and their sprouting responses to air drying. Proceedings National Acadamy of Science, India (Section B) 39:140-142.

Ueki, K. 1969. Studies on the control of nutsedge (on the germination of a tuber). Proceedings Asian-Pacific Weed Science Society 2:355-369.

Waldecker, M. A. and D. L. Wyse. 1985. Soil moisture on glyphosate absorption and translocation in common milkweed (Asclepias syriaca). Weed Science 33:299-305.

Wilfret, G. J. and D. S. Burgis. 1976. Nutsedge (Cyperus rotundus L.) control using herbicides under fallow conditions. Proceedings Southern Weed Science Society 29:237-243.

William, R. D. and G. F. Warren. 1975a. Competition between purple nutsedge and vegetables. Weed Science 23:317-323.

William, R. D. and G. F. Warren. 1975b. Suppression of Cyperus rotundus L. in carrots with night applications of nitrofen or herbicidal oil. Weed Research. 15:285-290.

William, R. D., G. F. Warren and L. B. Giordanos. 1976. Seasonal activity of EPTC for Cyperus rotundus L. control in a tropical climate. Weed Research 16:217-222.

Williams, R. D., P. C. Quimby and K. E. Frick. 1977. Intraspecific competition of purple nutsedge (Cyperus rotundus) under greenhouse conditions. Weed Science 25:477-481.

Wills, G. D. 1975. Effect of light and temperature on growth of purple nutsedge. Weed Science 23:93-96.

Wills, G. D. and G. A. Briscoe. 1970. Anatomy of purple nutsedge. Weed Science 18:631-635.

Wills, G. D. and C. G. McWhorter. 1985. Effect of inorganic salts on the toxicity and translocation of glyphosate and MSMA in purple nutsedge (Cyperus rotundus). Weed Science 33:755-761.

Wyrill III, J. B. and O. C. Burnside. 1976. Absorption, translocation and breakdown of 2,4-D and glyphosate in hemp dogbane and common milkweed. Abstracts Weed Science Society of America #192.

Young, F. L., D. R. Gealy and L. A. Morrow. 1984. Effect of herbicides on germination of four grass weeds. Weed Science 32:489-493.

Zandstra, B. H. and R. K. Nishimoto. 1975. Effect of undisturbed soil period on glyphosate control of Cyperus rotundus L. Proceedings Asian-Pacific Weed Science Society 5:130-133.

Zandstra, B. H. and R. K. Nishimoto. 1977. Movement and activity of glyphosate in purple nutsedge. Weed Science 25:268-274.

Zandstra, B. H., C. K. H. Teo and R. K. Nishimoto. 1974. Response of purple nutsedge to repeated applications of glyphosate. Weed Science 22:230-232.

Zentmyer, G. A. and J. G. Bald. 1977. Management of the environment. Pages 121-144. In J. G. Horsfall and E. B. Cowling (Eds.), Plant disease: an advanced treatise. Volume I. How disease is managed. Academic Press, New York.